100% renewable electricity

A roadmap to 2050 for Europe and North Africa

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PricewaterhouseCoopers

Potsdam Institute for Climate Impact Research

PIK

IIASA

International Institute for Applied Systems Analysis
www.iiasa.ac.at

ECF
European Climate Forum

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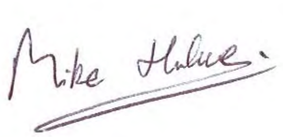
1. Foreword

In the last few months, organisations like the Intergovernmental Panel on Climate Change have received negative publicity, and the public may have lost confidence in some of their published findings. The public may have also lost confidence in the ability of countries to negotiate a global agreement in the context of the United Nations Framework Convention on Climate Change. What remains absolutely clear, however, is the importance of avoiding dangerous climate-related risks, while meeting the growing energy and development needs of an expanding world population. This will require rebuilding the energy sector in Europe, and expanding it globally, so that it does not emit CO_2 and other greenhouse gases.

Over the last five years, economists from across many countries have tried to anticipate the net costs to society of achieving this task. One example of this work was the EU-funded ADAM project, which I led, and which gathered the most respected energy-economic modellers from across Europe. All of their results point to the same basic conclusion: the total economic costs to society of restructuring the energy system will be small. At most, these costs will be a few percentage points of gross domestic product (GDP) over the coming decades. This would mean delaying the time by which countries grow to a given level of GDP by a single year, such as from 2050 to 2051. If restructuring the energy system to solve climate change is relatively inexpensive, then why haven't countries done it already? The reason seems to be the political and regulatory challenges. Policies makers will need to rewrite existing legislation to change the rules and the incentives guiding participants in the energy market. Researchers have only started to investigate how they should do so.

This report represents a major milestone in that effort of unravelling the Gordian knot of policy, and finding workable solutions. The authors focus on the power sector in Europe and in the neighbouring region of North Africa. Given a likely transition towards using electricity to power a greater share of transport, the power system will be the cornerstone of the energy system. The power sector in Europe is already highly regulated, with the regulations designed to achieve reliable and secure supply, at affordable prices. Despite these regulations, much of the infrastructure is aging and inadequate. Thus, any rewriting of policy will have to provide incentives to build new and better infrastructure, while maintaining security of supply and system reliability, all in the context of a move away from fossil fuels.

Harnessing and optimising renewable power generation to deliver reliable and continuous supply for Europe requires the integration of a geographically and operationally diverse range of supply sources – such as the vast concentrating solar potential of the arid deserts of North Africa, the hydro capability of hill and mountain regions, onshore and offshore wind farms and the capture of ocean tidal and wave power. The technological capability for developing these forms of power generation is already in place, or emerging and envisaged, and the economics of the key technologies is improving, albeit in a difficult financing environment. This report focuses on the pan-regional policy and market developments that would be necessary. They are enormously challenging, but the 2050 roadmap in this report shows how they could be developed.



Professor Michael Hulme

University of East Anglia, UK

Founding Director of the Tyndall Centre for Climate Change Research (2000-2007)

What will history tell us?

What would we do if we had access to clean and affordable sources of electricity, 24 hours a day without any negative environmental consequences? In addition to sustaining our current way of life, new opportunities would arise that to date had been set aside as too difficult or too expensive. Across Europe we might want to introduce electro-mobility on a mass scale, encouraging day to day transport of people and goods without the CO_2 penalty that came with the use of fossil fuels. In North African countries, the provision of reliable and potentially unlimited solar electricity supplies could provide a basis for substantial social and economic development across the region. These developments would also fit well with our ongoing efforts to both conserve energy and improve energy efficiency.

Most people would probably welcome a move to such a way of life. At various points in the last 150 years mankind has flirted with opportunities that could have led to such an existence. In the 1880's experiments with renewable energy technologies started in earnest and led to the development of commercial scale solar plants. Before they had a chance to become embedded in the power sector, these experiments were abandoned with the outbreak of World War I and the discovery of cheap oil. In the 1980's, after the 1970 oil price shocks, similar experiments with renewable energy began again. Government investment in a variety of renewable technologies from solar to ocean thermal looked at whether these could be scaled up in such a way that they could provide self-sufficiency for nations. And again in the late 1980's these came to a stop when oil prices remained stable and affordable and interests turned elsewhere.

Today we face a very familiar situation. Oil prices have been difficult to predict and, at times, have created economic uncertainty and volatility. Carbon pricing has added a new dimension, in Europe at least. Governments have again been increasing their investment in renewable energy technologies using a variety of tools at their disposal. But what can we do differently this time to ensure that this interest and intent to harness renewable energy on a commercial and regional scale succeeds?

2.

Executive summary

“This report gives a comprehensive outlook towards an electricity system for Europe and North Africa based completely on renewable energy in 2050. Its particular value is pointing out that this will be the result of an evolutionary development mainly of the economical, legal and regulatory framework and does not require fundamental technological breakthroughs. Most of the required technical components are available in principle already today. This is a sound basis for the roadmap.”

Jochen Kreusel

Head of Marketing and Sales Power Technologies, ABB Germany
Chairman of the Power Engineering Society of Germany

2. Executive summary

The combination of increased demand for electricity and security of supply is a very powerful driver of major power sector change in Europe and worldwide. Currently, for example, about 50% of Europe's energy demand is met with imported fuels and there are projections that this could increase to 70% in the coming decades[1]. Economic development and increasing use of electricity-consuming devices will increase future demand for electricity.

Alongside demand and security of supply issues, climate change also poses a global threat. Substantial and fairly rapid decarbonisation of electricity generation and many other sectors will have to take place if the world is to have any chance of staying within the 2°C goal for limiting the effects of global warming. In Chapter 3, we look at these and other challenges facing the region's current power systems and examine whether a vision of Europe, in combination with countries in North Africa, developing an integrated power grid with 100% of electricity generation coming from renewable sources by 2050 is possible. The import of renewable power from North Africa is key to the vision to ensure market competiveness under the land area constraints faced by Europe.

The key components of such a vision are:

- A regional power system based on a SuperSmart Grid;
- The rapid scaling up of all forms of renewable power, with the ultimate goal of decarbonising electricity generation in Europe and North Africa;
- A unified European power market that is united with the North African one, allowing for the free trading of electricity between all countries;
- The production of electricity at the most suitable sites by the most suitable renewable technologies; and
- Affordable electricity for each European Union and North African country and the eradication of energy poverty.

In Chapter 4, we set out a roadmap that outlines what European Union and North African (EU-NA) climate change and energy policy developments need to occur in the period to 2050 if this vision is to be achieved. Supported by a coherent policy transition, such a roadmap of activities could support the delivery of a sustainable, reliable and integrated power system for EU-NA. It proposes a holistic view, taking into account existing infrastructure and electricity generation capacities, and illustrates the necessary market, financial, infrastructure and policy milestones that would need to be put in place. It also considers other drivers and forces that could either promote or hinder the vision and suggests ways in which these could be managed for success.

Of course, in addition to renewables, there are other routes to addressing these concerns – most significantly, the expansion of nuclear power and the development of carbon capture and storage (CCS) from the burning of fossil fuels. Our exclusion of these routes from this report is not intended as any comment on their merit. Our goal is to examine what it would take to shift even further to a 100% renewable electricity supply.

The 2050 vision requires simultaneous and coordinated progress on many fronts – finance, technology, research and development (R&D), the development of adequate supply chains, change in generation mix and grid capability. Our 2050 roadmap identifies the key enabling areas to be government policy, investment, market structure, and infrastructure, and outlines the developments needed in each to achieve the 2050 vision. The developments in each are considerable and complex but we believe they are achievable.

- **Policy:** At a European policy level there is a need to build on the existing EU directives. The setting of firm and binding targets for Member States for 2030 to 2050 to inform the strategic planning process will require further guidance and new directives. This would include, for example, guidance to support the implementation of Article 9 of the Renewables Directive dealing with imports of electricity, and the development of a new directive on grid regulation which would mandate long term EU-level planning of grid infrastructure. These actions would, in turn, allow national renewable energy targets and incentive structures to reflect more ambitious targets in the short term. To achieve the 2050 goal of 100% renewable electricity, policies would also need to incorporate mechanisms to disincentivise construction of new fossil fuel power plants. All of this is possible using the existing EU processes and structures. For North African countries, the more immediate need is the development of institutional capacity to support a move to greater use of renewables. Steps are underway already in a number of countries and, with further support from the EU, could be in place in the short term, allowing for closer policy negotiations with Europe for electricity trade and, in the longer term, greater alignment between EU and the North African energy policy.

- **Investment:** The costs associated with such a transition will not be insignificant. Experience to date with other large infrastructure programmes suggests that the financing and investment capacity is available, provided we can create the policy environment for projects and programmes. At this point in time large sums of money have already been pledged by Multilateral Development Banks (MDBs), the private sector and the EU to support the expansion of renewables across the region, in particular in North Africa. The challenge sometimes has been the availability of credible projects to unlock this funding. The policy changes outlined above and ongoing technology developments will help to reduce risk premiums and provide certainty for investors. Better project information, better engagement with the renewables industry and better use of financial structuring experience will all help to turn these early projects into more mainstream investments for the financial community. As installed capacity grows, the track record of these early investments can then support the business case for larger and more ambitious projects.

- **Market structure:** Building on a trend towards a greater cooperation between individual EU power markets today, there will be a need for these to develop, first, into a smaller number of regional markets and then into a single EU regional market by 2020. The introduction of new long distance transmission infrastructure linking North Africa to Europe and real time pricing and support schemes, including mechanisms to reward dispatchability, will help stimulate this market unification process. Increasing connections and trade over time will then support the development of a unified EU-NA power market.

- **Infrastructure and planning:** The recent formation of two new organisations, the Agency for the Cooperation of Energy Regulators (ACER) responsible for developing common standards and approaches for cross-border trade and the European Network of Transmission System Operators for Electricity (ENTSO-E) promoting the reliable operation and optimal management of the European transmission system, will encourage centralised long term planning of the activities needed to the transform the existing infrastructure. The ability to deliver a significant increase in existing transmission and renewable generation capacity across the entire region will, however, be closely tied to developments in the policy and investment areas above. Over time, the existing infrastructure will begin to evolve to reflect the desired 2050 end state, with the completion of commercial scale demonstration plants, the ongoing development of renewable technologies, the adoption of these and associated smart technology into upcoming projects and the inclusion of increased amounts of storage and flexible reserves.

The summary of the key steps that need to take place on the roadmap from 2010 and 2050 is outlined in graphic form following this executive summary. Inevitably, given the magnitude of a vision of 100% renewable electricity for Europe, the ultimate feasibility of such a shift can only be fully judged as each stage in the shift is completed. The proposed step by step approach provides leaders with the opportunity to learn while doing and to adjust policies over time. It will also support the optimisation of cross-sectoral output while achieving the vision.

We conclude, in Chapter 5, by reviewing the critical question of cost and other key considerations that arise. The costs of switching to a 100% renewable electricity future need to be more fully explored. The most recent economic models show that the short-term costs of transforming the power system may not be as large as previously thought. Encouragingly, the costs of individual renewable technologies are continuing to decrease. Indeed, once this transformation has taken place, a power system based on low-cost renewable technologies is likely to be able to provide countries with opportunities for substantial economic growth and consumers with considerable - and growing - cost savings compared to a business as usual approach.

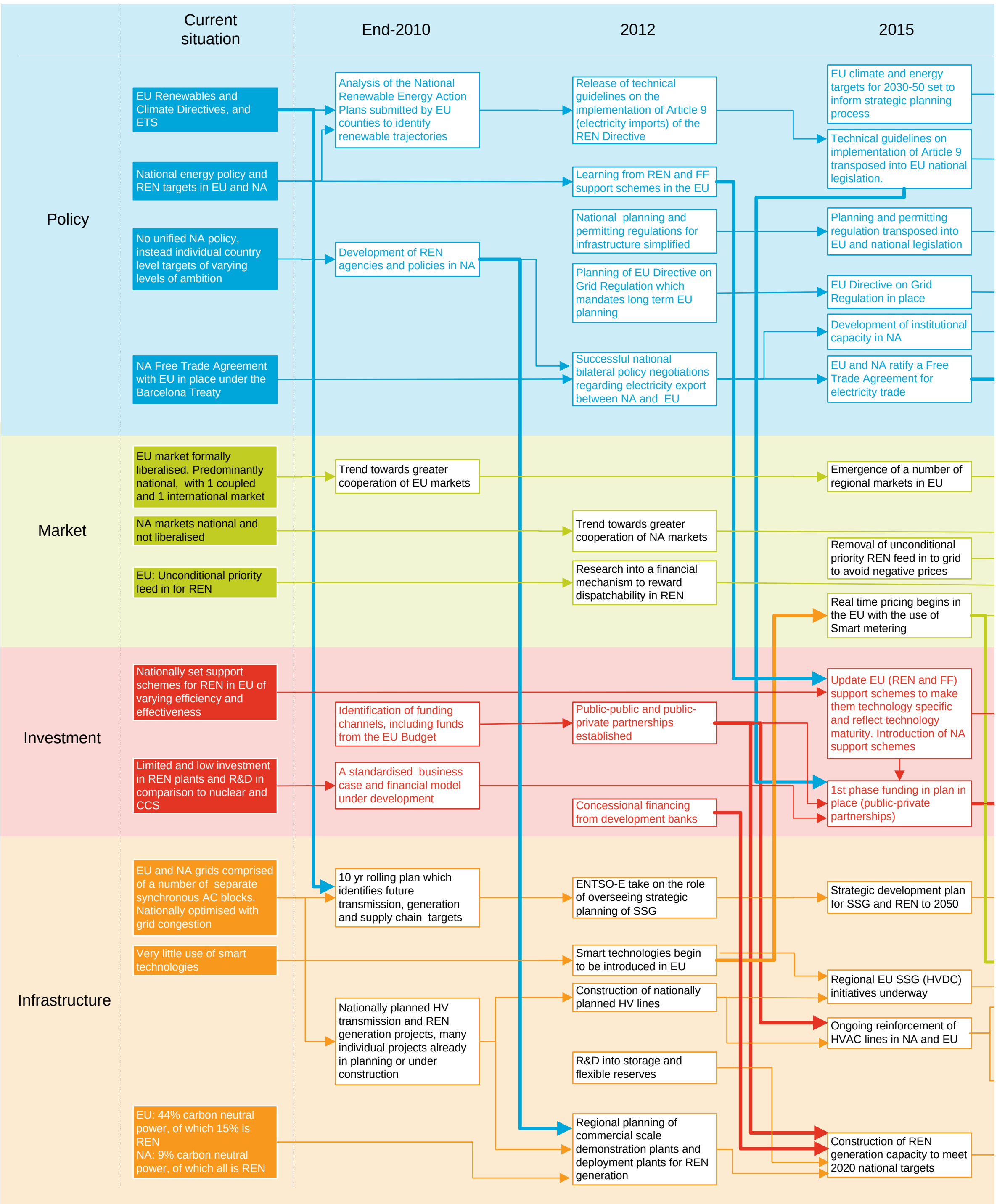
We also review the fresh challenges that, if it was achieved, a move to 100% renewable electricity would present. In particular, we look at the critical issue of energy security. Might a 2050 power system in which Europe relies on imports from North Africa threaten European energy security, rather than improve it? We conclude that, even with its heavy reliance on power from North Africa, the 2050 roadmap would actually lead to a net decrease in the reliance of the power sector on imported energy, as well as to a greater diversification of the countries from which those imports stem.

Timing is also important because, with the passage of time, the opportunity to meet the 2^{o}C goal for limiting the effects of global warming becomes more constrained. Small scale domestic renewable energy solutions will play a growing part, but there is a pressing need to identify and deploy larger scale solutions that can have a more dramatic impact on CO_2 emissions. The full potential of these solutions will, in many cases, necessitate international cooperation on a pan-regional scale to enable both their financial development and their physical implementation. If developed collectively, with sharing of investment costs and benefits, there are likely to be more viable opportunities that can be pursued.

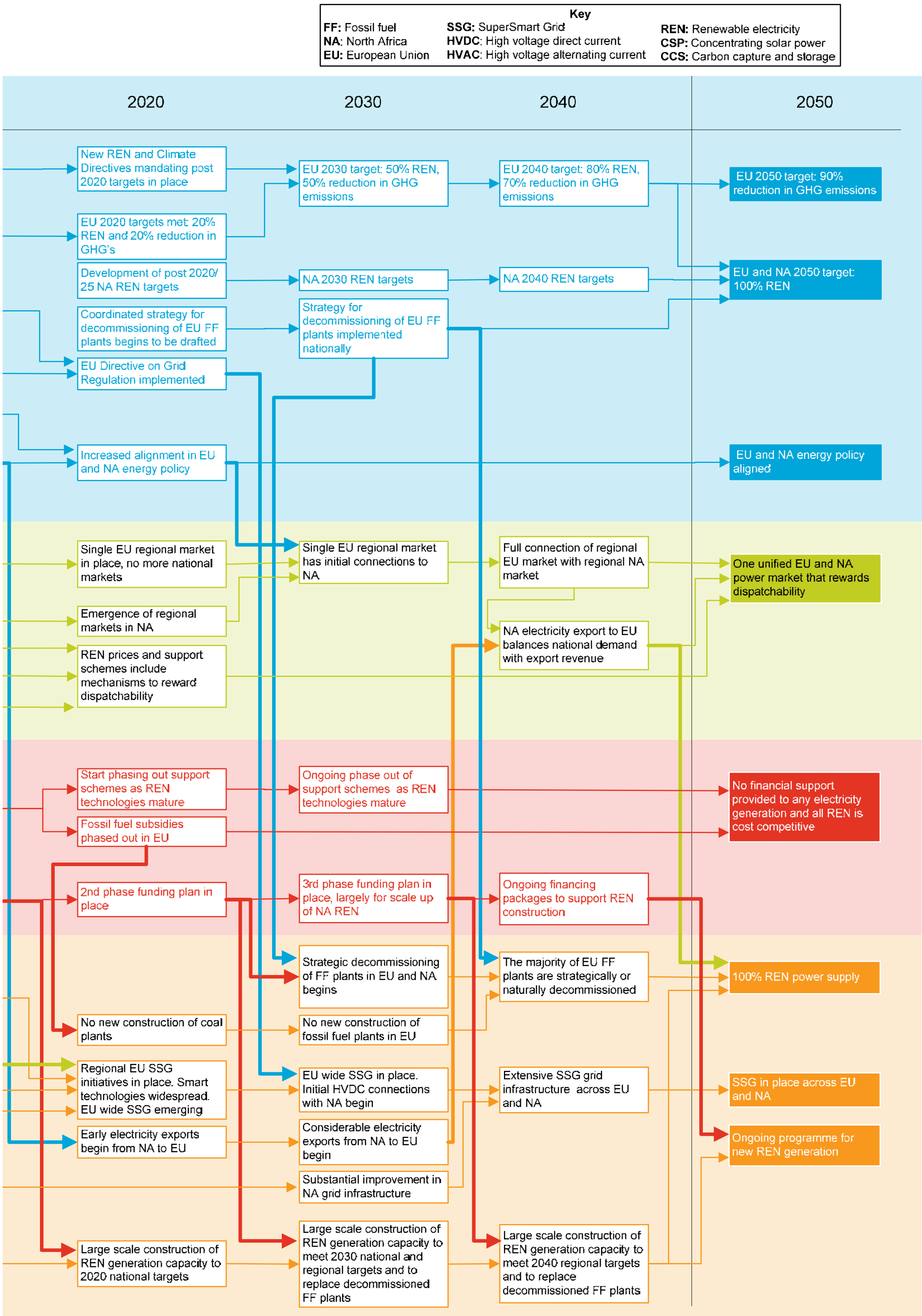
We hope this report will contribute to the development of new solutions to our energy and climate change challenges. The roadmap it outlines is intended to stimulate debate. It is also meant to show that we can be ambitious in our vision. We already have most of the necessary building blocks in place today – they perhaps just need to be configured differently. Finally, we hope that the report can support an ongoing and constructive ‘open source’ discussion between government, industry and other stakeholders across Europe and North Africa to deliver the change that is needed in the power sector in the coming years.

A Roadmap to 2050: Linking a 100% Renewable Power Sector with a SuperSmart Grid in Europe and North Africa

Our 2050 vision is one of a 100% renewable electricity in the EU and NA. To achieve this from the complex power system of today, there is no singular definitive or correct route, but rather a number of differing but complementary paths. This schematic illustrates one such roadmap. It is based on our assessment of the milestones required to achieve the vision, and should be considered as one potential way, not the only way, to do so.



We have identified four key enabling areas into which all essential activities fall: Policy, Market, Investment and Infrastructure. The interdependencies between these themes are critical to achieving the vision and are shown in bold. Milestones are stated for either the Europe, North Africa, or where no specific region is given the milestone applies to both.



3.

2010 to 2050: Today's situation, tomorrow's vision

"Humankind is facing two major global problems in this century: climate change and energy security. Renewable energies are the key for the solution of both problems as they are carbon free, abundant and sustainable. The proper combination of decentralised local renewable power generation and large solar power plants in the deserts has the potential to provide all the energy that will be needed. The precondition for this energy revolution is both a Smart Grid to manage the volatility of decentralised renewable power generation and a Super Grid to link large renewable power plants with the energy users over long distances."

Prof. Dr. Peter Höppe

Head of Geo Risks Research, Corporate Climate Centre, Munich Re

3. 2010 to 2050: Today’s situation, tomorrow’s vision

In this section, we look at the current state of the European and North African power systems and set out a vision for a sustainable power system for Europe and North Africa by 2050. We look in turn at the demand for electricity, the development of power grids, electricity supply and fuel mix, energy policy, power market structure and pricing and the cost of renewable electricity. For each of these topics, we discuss the challenges facing Europe and North Africa today and then look ahead at our vision for 2050 and how these challenges can be overcome.

The panel overleaf provides an overview of our vision of 2050. Our focus is on 100% renewable electricity. Such a focus enables us to consider what it would take to deliver a truly ‘quantum leap’ shift that addresses carbon reduction and energy security. Of course, in addition to renewables, there are other routes to addressing these concerns – most significantly, the expansion of nuclear power and the development of CCS from the burning of fossil fuels. Our exclusion of these routes from this report is not intended as any comment on their merit. Our goal is to examine what it would take to shift even further to a 100% renewable electricity supply.

Three objectives currently underlie European energy policy - competitiveness, security, and decarbonisation. They form the starting point for our 2050 vision. An ambitious move to renewables would be a huge and dramatic way of fulfilling the goal of decarbonising the power sector. If we are to deliver competitiveness then all customers must be able to continue to access as much electricity, at affordable prices, as they need. Given constraints in the land area available in Europe for renewable energy, in order to ensure competitiveness, a vision of 100% renewables will require Europe to import some of its renewable power from North Africa[2] and, therefore, the development of substantial renewable supply from North Africa is a key part of our vision.

Finally, achieving security, given flows of power from North Africa into Europe, will in turn require the integration of Europe and North Africa into a single, well-functioning market, where all countries involved have an incentive to see the smooth flow of electricity and revenues as being in their own continued self-interest. It also implies that North Africans will need to have fair and affordable access to electricity, in turn requiring a sharp rise in capacity to serve the North African segment of the market, so that the mutual security of supply for both North Africa and Europe is maximised. We discuss the issue of security of supply and these other issues in more detail later in the report.

Overview: 2050 vision

The key components of the 2050 vision are:

1. A regional power system based on a SuperSmart Grid;
2. The rapid scaling up of all forms of renewable power, with the ultimate goal of decarbonising electricity generation in Europe and North Africa;
3. A unified European power market that is united with the North Africa one, allowing for the free trading of electricity between all countries;
4. The production of electricity at the most suitable sites by the most suitable renewable technologies; and
5. Affordable electricity for each European and North African country.

The three objectives underlying current European energy policy: competitiveness, security, and carbon neutrality, drove the design of the 2050 vision. Satisfying these and achieving a 100% renewable electricity system implied several important design features. Without relying on major new construction of fossil fuel, CCS or nuclear power, achieving carbon neutrality meant replacing current fossil fuel generation with renewables. Achieving competitiveness meant allowing European industry to continue to access the electricity at affordable prices. With land constraints, Europe had to import some of its renewable power from North Africa. Achieving security, with flows of power from North Africa into Europe, in turn required the integration of Europe and North Africa into a single, well-functioning market, where all of the countries involved had an incentive to see the smooth flow of electricity and revenues. With North Africans also requiring fair and affordable access to electricity, a sharp rise in overall capacity was also needed.

Key attributes of the 2050 vision

- The electricity supply system of North Africa and Europe in 2050 is 100% renewable, following a continuous and steady transformation of the power system in parallel with sustained growth in demand.
- The grids of North Africa and Europe are strongly interconnected. This has been achieved through the reinforcement of the high voltage alternating current (HVAC) grid, a pan-European, cross Mediterranean overlay high voltage direct current (HVDC) Super Grid and the introduction of Smart technologies and a Smart Grid. Together this comprises a SuperSmart Grid.
- The renewable power mix is geographically optimised, with production at the most suitable sites across Europe and North Africa. Wind generation in the windy North Sea region, concentrating solar power (CSP) with storage in the sunny south, biomass and wind in the Baltic Sea region and eastern Europe, and hydro in the mountainous regions of Scandinavia and the Alps.
- The North African and European energy policies are aligned and cooperative. A stable and predictable policy framework has been vital in achieving a 100% renewable power sector, as have financial incentives and support mechanisms, but these are now phased out.
- The European power market is unified and united with the North African market. This has been achieved by the gradual unification of regional markets, which have grown organically over time. An additional market which recognises and rewards dispatchability has also been introduced.
- All renewable technologies in use have experienced significant cost reductions in capital and operational costs along with improvements in efficiency. They are now competitive. Their supply chains constitute a mature and strong industry and the renewable power sector is an important employer of skilled workers in both regions. Almost all citizens have access to affordable electricity, especially in North Africa.
- The European Union Emission Trading Scheme (EU ETS) and the price of carbon have played a key role in encouraging a shift to greater use of renewable energy by 2050.

3.1. Electricity demand

3.1.1. Demand: Today's situation

The current power systems of Europe and North Africa are very different in most respects, mainly due to the large differences in economic development and the abundance of oil and gas in North Africa. European power consumption is 3300 TWh/a, whereas the five North African countries have a cumulated power demand of 180 TWh/a, of which almost 100 TWh/a is consumed and produced in Egypt[3-4]. North Africa, excluding Egypt, thus has a power consumption that is lower than the consumption in the Netherlands alone.

Despite this, North African electricity demand has increased rapidly, almost doubling in size in the last 20 years. It continues to increase by up to 8% year, which makes it one of the fastest growing power markets in the world. This growth mainly reflects rapid population and economic growth, as well as social development and urbanisation[5]. European demand has steadily increased by 1-2% per year, and has consequentially grown 30% between 1990 and 2006[3-4, 6-7]. It should be noted, however, that the European consumption growth rate of 1.5% in 2005 corresponded to an absolute increase of 50 TWh/a, whereas a North African growth of 8% per year meant an absolute growth of 15 TWh/a. European power demand is therefore increasing faster than North African in absolute numbers.

3.1.2. Tomorrow's vision: Greater demand but new efficiencies

In 2050, we envisage that the EU-NA power system will have a total electricity consumption of at least 5000 TWh/a, with approximately 25% of this demand in North Africa and the remainder in Europe. In total, only 60% (3000 TWh/a) of the system-wide electricity supply is produced in Europe, whereas 40% (2000 TWh/a) is produced in North Africa. Thus, a large fraction – 20% – of European electricity is produced in North Africa.

The demand increase (+400 TWh/a compared to today[3]) in Europe originates mainly from a fuel switch to electricity through the introduction of electric cars, amongst others. The European economic growth roughly cancels the electricity efficiency gains achieved during the same period (assumed +2%/a for both). The North African demand in 2050 is some 700% higher than today[4]. The increase is mainly driven by population growth (100 million more citizens in 2050 than today) and strong economic growth, accompanied by only small increases in electricity efficiency. These figures lie within the range of most power system scenarios[6-8], including scenarios which consider renewable power trade between EU countries[9-10] or between EU and North Africa[5, 11].

3.2. Power grids

3.2.1. Power grids: Today's situation

The European and North African power grids are, with the exception of a few submarine HVDC cables, completely based on alternating current technologies. The European power system is split into five synchronous grids - the Nordic and British grids with a consumption of 400 TWh/a respectively; the Baltic and Irish grids with consumptions of around 30 TWh/a each; and the fifth grid which is the largest and covers all of continental Europe, with a consumption of 2600 TWh/a (including the non-EU members). This is the largest synchronously working machine in the world[3, 12-13]. The three western North African grids are synchronous with the continental European grid, whereas the Libyan and Egyptian grids are synchronous with Jordan, Lebanon and Syria[14].

All these blocks are interconnected with HVDC back-to-back facilities or HVDC subsea cables[15]. Currently, there are no significant HVDC connections on land in Europe, except some very limited back-to-back connections to asynchronous areas, mainly to the Russian grid.

Two particular areas are worth looking at in more detail. These are grid congestion and grid expansion planning and regulatory constraints.

Grid congestion

The blocks comprise a number of different national or regional markets and control areas. The intra-European interconnection capacity is still rather small and congestion is a problem at most national borders, a problem that is strongly accentuated by the regional expansion of intermittent renewable power, especially in northern Europe[16-18]. The power grids have been constructed from a national perspective, although the European markets have been interconnected and, in the case of continental Europe, synchronous for decades. Therefore, there was no urgent need for interconnections in the past and only a few were built. Over time, the benefits of stronger interconnections, like the efficient sharing of control capacities and imports during capacity shortages, became apparent and the interconnections were reinforced.

However, the interconnections are still not strong enough to unify the continental European markets effectively; these remain fragmented and often physically separated due to congestion. Because it is based on AC technology and because of congestion at the national borders, the grid is currently not strong enough to generate the benefits of a Super Grid, although the power system stretches over a large enough area. The limited interconnection capacities cause both market distortions and physical problems: the increasing trade, coupled with very strong growth in wind power in geographically limited areas, cause local overloads and an increasingly urgent need for new power lines. This is already an issue today during normal operation. At times after the failure of a large line, generation or load unit, the overloads can reach unacceptable levels and the stability and synchronous operation of the grid are threatened. A recent study identified 19 transmission grid segments with overload (up to 160%) during strong wind conditions, and three segments with overload (up to 150%) even during normal operation and strong wind, only in Germany[16].

The congestion in some national markets, most significantly the German and Danish systems, has repeatedly led to negative electricity prices during high wind and weak load times. In 2006, the West-Danish system area had negative prices for more than 200 hours, but this was reduced to 50 hours in 2008. Germany experienced 60 hours of such between October 2008 and October 2009, with a record negative price of -500 €/MWh.

The negative prices have acted as a wake-up call for many decision-makers and grid expansions are an increasingly hot topic in the wind-dense regions across Europe. Different measures for grid integration are being discussed and some are being pursued, ranging from greater interconnection capacity to the permanent throttling of wind power, allowing the windmills to regulate their output upwards and downwards[19-22]. In most areas in Europe, however, grid integration is not yet a relevant problem because the shares of intermittent renewable generation are very low.

Grid expansion planning and regulatory constraints

Despite regional grid integration difficulties, the feed-in of renewable electricity is still prioritised before fossil and nuclear power in all EU countries, and will remain so under the new Renewables Directive. This priority access is key to the successful expansion of renewable power in many countries. However, grid access is still a major obstacle for the expansion of renewables, especially the high connection costs and very long lead times involved. The average time to get permission for the construction and grid connection for a renewable power plant in the EU is about 30 months, with Ireland, Denmark, Spain and Sweden approaching or exceeding 50 months. Many countries have complicated permission processes for the construction and grid connection of renewable power plants: in Hungary, 40 different authorities are involved in the permission processes and almost 100% of all applications are denied, compared to the EU27 average of 5 different permission authorities and 30% rejections[23-24].

The situation is even worse for the construction of transmission lines: the time from the start of planning to the issuing of the building permit for a Trans-European Energy Networks priority electricity transmission project is on average seven years, with 25% of projects requiring more than twice this time[25]. The very long permission time for transmission lines in most European countries is an increasingly pressing problem. The long lead time, coupled with uncertainty about whether the building permit will indeed be granted be after years of planning and negotiations makes an investment in transmission in Europe unattractive. The permission difficulties are probably the major obstacle to building new power lines and, thus, one of the largest obstacles in the way of reaching 100% renewable power supply by 2050.

The grid bottleneck is further aggravated by the fact that grid regulation is handled nationally rather than at a European level, and is required to be economically efficient in a medium-term perspective rather than long term. This effectively prohibits the construction of land-based HVDC lines, which are more expensive than HVAC lines over short distances, because no European country is large enough to allow HVDC lines to reach the economic break-even point with HVAC, at around 800 km[5]. This form of national regulation also complicates the regional coordination of renewables expansion and the grid connection of new capacities. All in all, the picture is clear: due to complicated permission processes and a geographically and temporally limited grid regulation, Europe has a long way to go if its grids and renewable capacities are to be efficiently unified in the long term.

This problem has been acknowledged by some. In order to stimulate the coordinated construction and more efficient use of new interconnectors, as well as to increase the cooperation and coordination between TSOs, the European Commission established two new organisations in 2009. ACER has the aim of developing common standards and approaches for cross-border trade, and ENTSO-E aims to promote the reliable operation and optimal management of the European transmission system. Still, it remains to be seen what problems can be solved by these new agencies and which problems will persist.

2010: Power system constraints

Transmission: Within Europe most of the existing transmission infrastructure will struggle to cope with the expected increase in future electricity demands outlined in this chapter. Strategic planning at a European level is needed to determine the future grid architecture and to identify the new technologies e.g. HVDC, that may be needed to satisfy demand and allow a greater integration of renewables in the future.

Investment costs: Simply keeping up with increasing electricity demand is likely to require significant new investment in infrastructure. If low carbon technologies are included, this figure increases further. Whilst there is a need to manage the demand for electricity so that it remains affordable, it is also critical that the right technology options are chosen for future investment.

Energy strategy: Continuing price volatility, concerns about security of fossil fuel supply and increasing electricity demands mean that business as usual approaches will not be viable. Energy efficiency and conservation should be at the core of any government energy policy discussion, independent of the technologies or scenarios favoured to meet future demand.

3.2.2. Tomorrow's vision: A pan-European, cross-Mediterranean SuperSmart Grid

A pan-European, cross-Mediterranean SuperSmart Grid is the key enabling development for our vision of 100% renewable electricity generation in Europe and North Africa by 2050. The unification of the European and North African markets would require an overlay HVDC Super Grid, a strongly reinforced HVAC grid and the area-wide introduction of Smart technologies and Smart Grids. All bottlenecks at artificial obstacles, such as national or legislative borders, would need to be removed. In particular, the North African HVAC grids and interconnections would need to be expanded and all North African off-grid electrification schemes integrated into the synchronous EU-NA system (except UK and Ireland, which would still only be connected to the continent via HVDC cables). In 2050, almost all citizens in the entire European-North African area would be connected to the HVAC transmission grid.

The HVDC grid is a key to a fully renewable power supply[11]. It has two primary tasks: to transport renewable electricity from production sites in North Africa and peripheral regions of Europe to load centres and to transport electricity away from areas of momentary excess supply to areas with momentary short supply. The HVDC grid thus plays an important role in stabilising the underlying HVAC transmission system.

In our 2050 vision, the only imports into the European power system would be the renewable power imports from North Africa to Europe (about 750 TWh/a) which would be enabled by a large number of separate cross-Mediterranean HVDC links. These lines would need to be fully integrated into the overlay grid, which increases both the redundancy of export/import trading lines and the security of supply in the entire system. The reliability of the system would be at least what it is in Europe today[26]. The feed-in points for electricity imports into the HVAC system would be the same as the feed-in points from the general HVDC grid and the final destination of the imported electricity will, just as for domestic European electricity, depend on the production and loads in other parts of the system.

3.3. Electricity supply

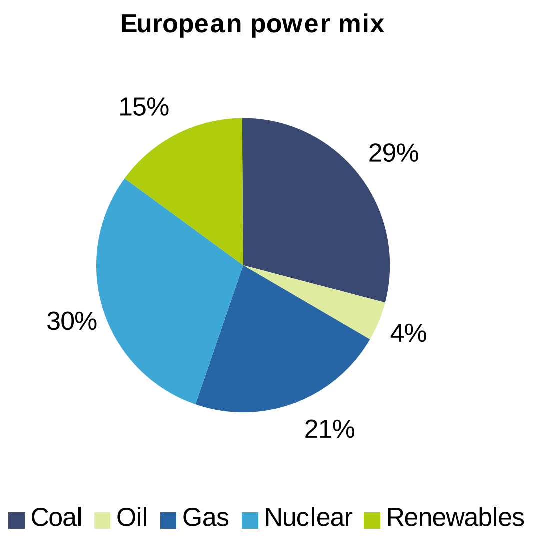
In looking at electricity supply, we have addressed two areas in detail:

- The fuel mix that is used to support electricity generation; and
- The energy import and security of supply issues.

We look first at the situation today and then at our vision for 2050.

3.3.1. Fuel mix: Today's situation

The fuel mixes in both Europe and North Africa are dominated by fossil fuels. Fossil fuels make up around 55% of the production in the EU and more than 90% in North Africa (see Figure 1).



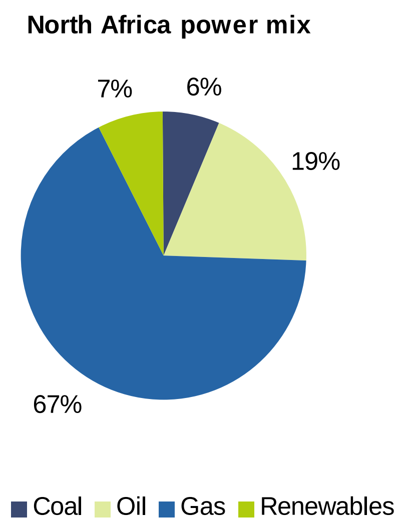


Figure 1: Electricity mix of European (EU27) and the five North African countries. The power system sizes were 3300 TWh/a and 180 TWh/a respectively (2006)[3, 4]

On a more detailed level, Europe has a very diverse power system and the fuel mixes differ significantly across Europe: some countries, like Poland and the Czech Republic, have power systems almost entirely based on coal, the French system is based on nuclear, whereas the Austrian system is based on large-scale hydro power[3].

The North African power markets are not as diverse and the national markets are comprised almost entirely of gas- and oil-fired generation (67% and 19%, respectively), mainly due to the abundance of these fuels in the region. The Egyptian system has a large fleet of gas and oil power stations, in addition to a large share of hydro power (13%), of which the vast majority is generated at the Aswan Dam. On the other hand, the Moroccan fuel mix is heavily dominated by imported coal (70%) due to the almost complete lack of domestic fossil fuel resources[4].

We now consider in more detail two key areas that impact the fuel mix: the trends within the renewables share of generation capacity and the age of the underlying assets.

Renewables share

The power sector is a major source of greenhouse gas emissions in all regions of the world. In the EU27, the power industry is responsible for a quarter of total greenhouse gas emissions, and a third of CO_2 emissions. European power sector emissions decreased during the 1990s, but have increased again and are today only 5% lower than in 1990[3]. Some 45% of the European power supply is effectively zero carbon, comprising 30% from nuclear power and 15% from renewable sources (see Figure 2). The renewables share is made up of (9%)[27] from old, large-scale hydro power and only 6% from new (younger than 10 years) renewable power plants. The growth in renewables is very modest across Europe as a whole.

There are significant differences in renewables growth: some countries, like Denmark and Germany, show strong growth rates (60% and 80% renewable energy growth since 2000), whereas other countries, most significantly France and Austria, have decreasing shares of renewables due to increasing electricity demand and stagnating renewable capacities. The expansion of renewables is strongly focused on the original Member States of the EU15: no new Member State has more than 1% of its electricity mix from renewable sources other than old, large-scale hydro[27].

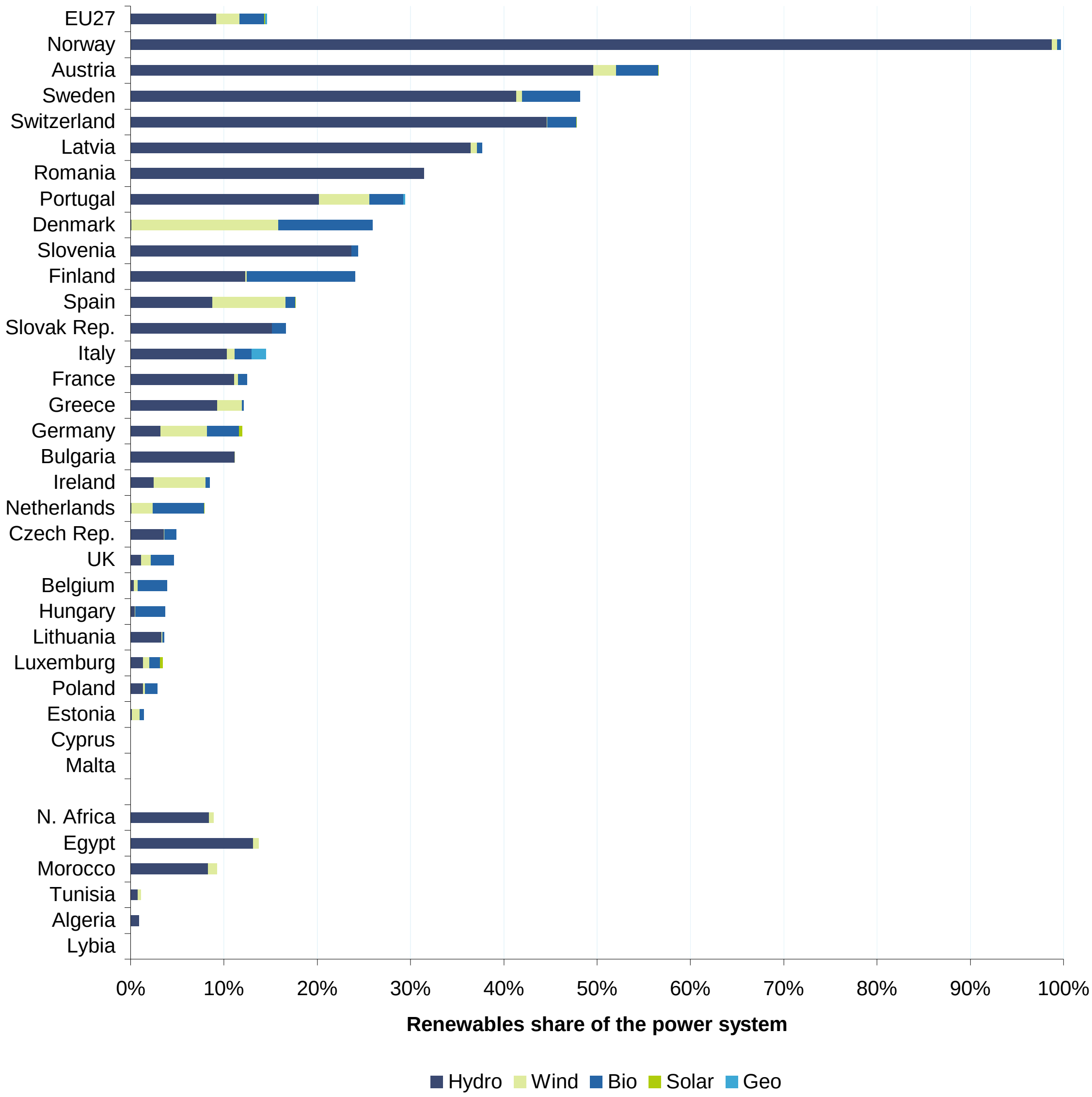


Figure 2: Renewable electricity shares in EU27 and North Africa[4, 27]

Most of the growth in European renewable electricity is in biomass and wind power, which have grown by 40 and 60 TWh/a since 2000, respectively. Two thirds of the new wind power capacity has been built in Germany and Spain and one third of the new biomass power is in Germany[27] - powerful evidence of the successful implementation of feed-in tariffs for renewable power in these countries.

The construction of CSP plants in Europe has recently increased and is almost entirely based in Spain, driven by the Spanish feed-in tariff regulations. At the end of 2009 Spain's CSP industry boasted 250 MW installed capacity, 800 MW under construction, 2000 MW at pre-construction stage and another 10000 MW in planning[28].

The North African power sector is the largest CO_2 emitter in the region, even dwarfing the large oil and gas refining industry[29]. The North African share of renewable electricity is 9% (16 TWh/a), of which hydro is 8.5%, almost wholly generated by the Aswan Dam in Egypt[4]. CSP and CSP-fossil hybrid capacities (totalling 900 MW) are planned in Morocco, Algeria and Egypt and about 60 MW are currently in construction. A number of wind farms are planned in Morocco and Egypt[28-31]. Nonetheless, the growth in renewables has been and still remains weak.

Asset age

Large parts of the power plant fleet of the EU27 are old; there is therefore a need for new capacity to replace obsolete power plants as well as meet increasing demand. About a third of the coal, gas and nuclear power capacities are older than 20 years but only 15% are 10 years or younger[32]. Given the expected 40 year life time of these power plants, the aging of the generation capacity should not lead to any capacity shortages in the short term. However, more than half of the coal capacity is over 30 years old, and the replacement need will be large in the coming decade[33], see Figure 3.

As coal is typically the power source with the highest emissions, the decommissioning of existing coal fired plants may create the opportunity for the economic phase-in of renewable sources, particularly when this has a base load capability (e.g. CSP). By 2050, which is the timeline for this report, the reinvestment cycle will have run its course for all technologies and almost all existing power stations will have been replaced at least once.

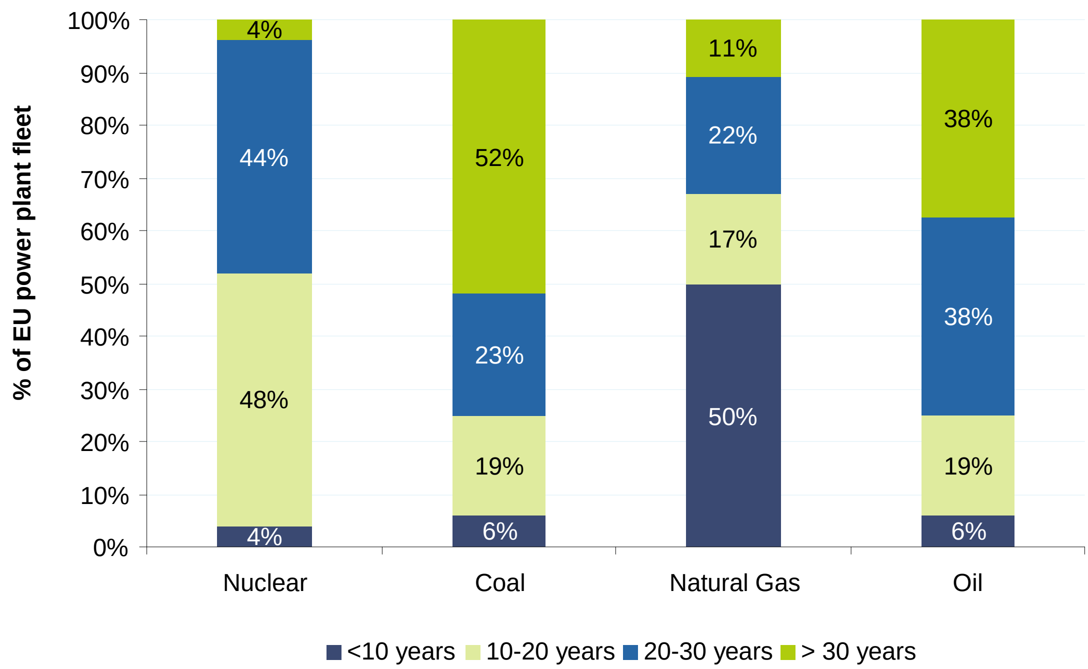


Figure 3: Age structure of the European (EU29) nuclear, coal, gas and oil power plant fleet[33]

The North African power plant fleet is younger than the European, mainly due to the rapid demand increase in recent years. Nonetheless, the replacement needs are significant here too: by 2020, 30% (Morocco, Algeria) to 50% (Libya) of the capacity will have reached the end of its normal life time and, by 2030, more than half of the existing power plants across the region will have to be replaced[34]. This coincides with the time that CSP is projected to become cost competitive with conventional technologies[35], which provides a strong argument for CSP; the natural decommissioning of fossil fuel power plants can be carried out as planned and the gap can be filled with base-load capable renewable power sources.

3.3.2. Tomorrow's vision: A geographically optimised power mix

In our 2050 vision, the development of a pan-European, cross-Mediterranean SuperSmart Grid would enable electricity production at the best sites for each technology, regardless of national or regional borders and distance to the central European load centres. This both increases the efficiency of the system and reduces the intermittency problems.

This would enable the development of a highly diverse mix of European renewable generation capacities at the most suitable renewable sites. It would combine both centralised generation through large, single units such as large CSP plants, offshore wind farms or large biomass power plants, and decentralised generation with small-scale units such as roof-mounted PV, smaller onshore wind farms and biogas power plants. Due to differences in geography and population density, the power mix, although very diverse at a European level, would still be skewed towards single sources in a national or regional perspective.

Regional SuperSmart Grid clusters would have developed to maximise the efficient use of local resources. The share of wind would be high in the windy North Sea region, the share of solar power high in the sunny south of Europe, whereas the Baltic Sea region and eastern Europe would be rich in both wind and biomass. The mountainous regions in Scandinavia and the Alps would provide hydro generation and storage resources. A general tendency would be that the peripheral regions, including North Africa, supply the central European regions with a share of their electricity supply. All clusters would be strongly interconnected via the HVDC transmission grid.

The North African 2050 power system would mainly be based on onshore wind power and solar (including CSP plants with storage and PV), with significant differences depending on resource availability. In some countries, especially on the western and eastern coasts, wind power would be dominant, whereas the majority of power generation in the central desert regions would be CSP. Because of the high overall share of CSP, electricity for both local consumption and for export would be completely dispatchable throughout the year[36], using CSP plants with storage, in conjunction with other renewables as appropriate.

North African exports to Europe would come from all countries in the region, but exports from Egypt would be limited by the large growth of its domestic electricity demand. In total, we assume that the North African countries would produce 60% more electricity than they consume in 2050 and that there would not be any interruptions in electricity trade between North Africa and Europe due to political conflicts. Intermittent sources such as PV would also be widely used in a decentralised manner to support off grid and small scale local demand.

3.3.3. Energy imports and security of supply: Today's situation

In considering electricity supply we now turn to a second area – energy imports and security of supply. Due to the historical growth of the power systems and the weak interconnections, most EU and North African countries are generally self-sufficient in electricity. Almost no electricity is imported or exported to or from the EU, and the power flows between the North African countries are only a fraction of electricity demand because the interconnections are very low. Only Finland (net imports 13%, from Russia), Italy (17%, from France), the Netherlands (15%, from different countries) and Morocco (10%, from Spain) rely heavily on continuous electricity imports. France, Germany and the Czech Republic are large electricity exporters and the largest electricity flows go from and through these countries[4, 14].

However, whereas most countries pride themselves on being autonomous in relation to electricity supplies, almost all European and North African countries are strongly dependent on imported fuels for their power generation, such as gas, coal and uranium. Only Poland, Czech Republic, Algeria and Libya are self-sufficient in fuels for the electricity sector[3-4]. In 2006, the EU imported just over half of its energy. Some 41% of coal, 84% of oil, 97% of uranium and 61% of gas were imported from non-EU countries[3, 37-38] (see Figure 4). Gas imports alone resulted in an economic outflow from Europe of €130bn at 2007-8 prices, although not all of this gas was used for power production. Only 15% of the EU27 coal, gas and uranium consumption originates from the Organisation for Economic Co-operation and Development (OECD) countries and the OECD share of the imports is rapidly diminishing against a backdrop of increasing imports to the EU. The majority of the new imports come from Russia, and this dependency is an issue of some concern, especially after the Russian-Ukrainian gas crises of 2006 and 2009.

Historically, the level of import dependency has not resulted in any significant service interruptions. Any blackouts in Europe have been caused by technical failures in power plants, grids, loads or operational errors. Nonetheless, maintaining or increasing the level of security of supply in Europe as domestic fossil fuel reserves are depleted is therefore one of the main drivers, if not the single most important one, for the ongoing restructuring of the power system.

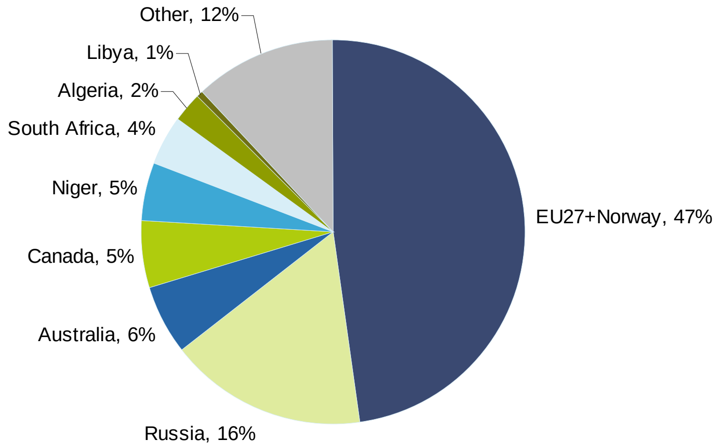


Figure 4: Domestic and imported sources of fossil and nuclear fuel for European (EU27) use (2006)[3, 6, 37-40]

The North African power sector is not nearly as dependent on energy imports as Europe. The reason for this is simple: Algeria, Libya, Egypt and Tunisia are net gas and/or oil exporters. As gas and oil dominate the power mix, there is no need for imports. Morocco, however, has a coal import dependency of almost 100% and, given the 70% coal share in the power mix, is therefore very dependent on foreign energy sources.

The Algerian and Libyan economies are heavily based on the petroleum industries, which in both countries comprise 30% of total GDP and 95% of export earnings. In Algeria, 60% of government income comes from oil and gas exports; for Libya, no data is available, but the situation is probably similar[41-42]. These countries are among the primary suppliers of fossil fuels to Europe and are connected via cross-Mediterranean gas pipelines to Spain (Algeria) and Italy (both). Their economies are very dependent on revenues from gas and oil trade, but these have proven to be highly volatile, mainly due to the volatility of the oil price (see Figure 5). The unpredictability of hard currency earnings has had a very negative impact on the economies of Libya and Algeria. For these countries, security of demand is a key driver for their energy policy and is at least as important as security of supply is for Europe.

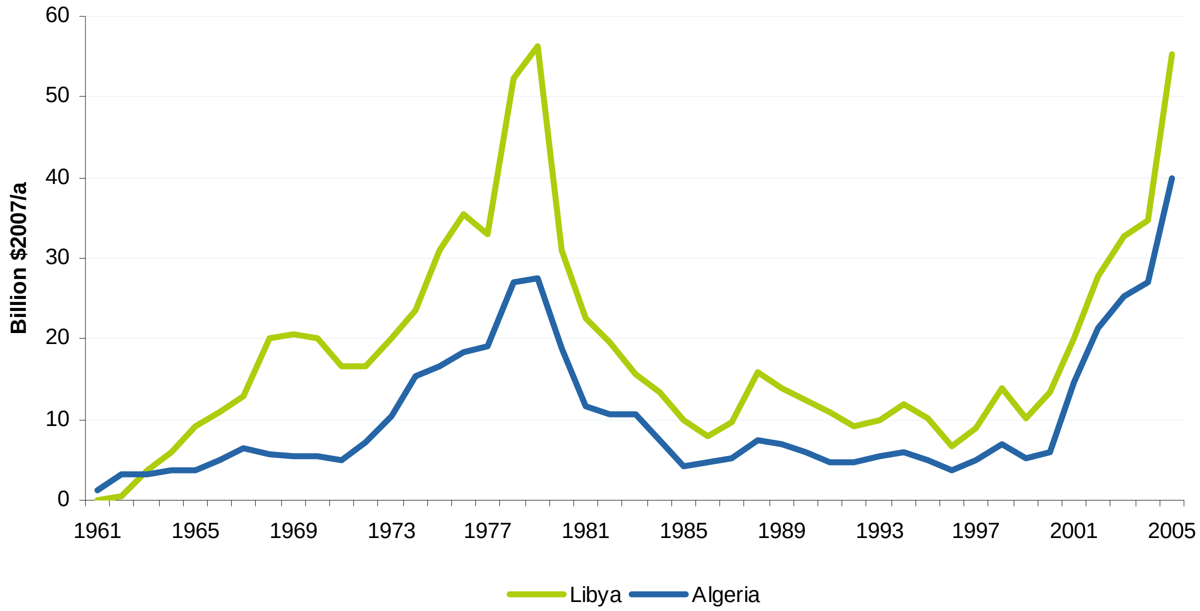


Figure 5: Value of Libyan and Algerian oil exports[43-47]

Despite the large fuel import dependency, the European security of electricity supply is currently very high, and has probably never been higher. As the grid grows, failures can be more easily absorbed because a disturbance represents a smaller share of total electricity flow than in a smaller system. When blackouts do occur, however, the risk of cascading is large, as was seen in the November 2006 blackout which cascaded from northern Germany to Morocco. The ENTSO-E grids are designed to absorb the failure of the largest unit (in continental Europe 3 GW) and to have enough spare capacity to immediately resolve at least 99.9% of all contingencies without blackouts[26]. The outage time in the European power grid amounts to only a few hours per year. In North Africa, rolling blackouts still occur, but grid stability and generation adequacy is generally improving.

3.3.4. Tomorrow's vision: Energy self-sufficiency in power generation

In our 2050 vision, the electricity supply system in 2050 is larger than today, both in terms of geography and electricity consumption, and is 100% renewable. There has not been any sudden, large expansions of the power system; the transformation to a 100% renewable power supply has been continuous and steady. There is an inherent security of supply because all electricity is generated from renewable sources.

European and North African countries have supported the domestic expansion of renewable energy generation, focusing on technologies appropriate for their resource profile. Wind generation has expanded across the North Sea region benefiting from the development of the North Sea Grid project. CSP with storage and PV have developed across southern Europe and subsequently in North Africa, allowing lessons learned from European expansion to inform the planning and construction of substantial new generation infrastructure in North Africa. Biomass and wind generation capacity have also been supported across the Baltic region and eastern Europe. Finally, hydro generation capacity has been maintained and encouraged where possible across Scandinavia and the European Alps.

The result of all of this activity has been that each of the individual countries in the region has been able to play a large role in meeting a part of EU-NA's overall renewable power supply. The ability of countries to supply 100% renewable electricity has in turn resulted in a greater self sufficiency and improved reliability of supply to meet their own domestic needs.

The roadmap technologies

We have mentioned a number of times that renewable technologies present an opportunity to transform the power sector. But what do we mean by renewable technologies and how do they compare? In this section we provide a brief outline of the main renewable options that exist today that could be considered for the 2050 roadmap.

Hydropower

Hydropower is the largest source of renewable electricity in Europe, supplying 60% of Europe's total renewable energy. Depending on the location, hydro can be cost competitive with coal. Hydropower is especially important for a renewables-only power system because it is dispatchable and, when combined with pumping water uphill, can be used to store excess power. However, two factors limit the continued expansion of hydropower. First, future capacity is limited by geographic factors. In western Europe, the economic potential of hydro is about 30% greater than current utilisation, while in south-eastern Europe it is double[48]. Second, environmental concerns such as the loss of land, habitat and the displacement of settlements is limiting development of hydro in countries where there is substantial resource, such as Austria.

Wind

Wind power has been the fastest growing of the European renewables. At the end of 2007, it accounted for 52 GW of installed generating capacity, supplying 3.8% of the EU-27 total electricity consumption[49]. It accounts for the second largest share of renewable electricity in Europe, after hydropower. Feed-in tariffs in Germany and Spain have contributed to this growth and these two countries account for approximately 50% of the installed wind generation capacity in Europe. Denmark has the highest proportion of wind in its power mix, at 20%[50].

One of the major reasons for the growth in wind is that it is currently the lowest cost renewable energy source. Onshore wind power, at prime locations, can cost as little as €0.065/kWh whilst the lowest offshore costs are €0.09/kWh (see Appendix 3). The development of offshore wind has been low in comparison to onshore wind, mainly because the costs are, at present, higher than for onshore wind at good sites[51].

For OECD Europe as a whole, it has been estimated that it would be possible to obtain approximately 1000 TWh/yr of onshore wind at a cost of less than $0.07/kWh (€0.05 /kWh), and about 2 500 TWh/yr at a cost of less than $0.10 / kWh (€0.07/kWh)[52]. In practice, however, it will not be feasible to develop all of the sites that are suitable for wind power[2] and due to the intermittency of wind, achieving high penetration of wind power would require significant long-distance power transmission, spreading local wind conditions over a continental scale.

Photovoltaic solar power

Photovoltaic solar power (PV) generates electricity using the conducting properties of certain chemicals, most importantly silicon. PV has been growing quickly, although it still represents only 9 GW of total capacity in Europe. In 2002, there were 550 MW of new PV cells installed. By 2007 it was more than 3 GW[53].

PV, however, has two major constraints: cost and intermittency. In terms of cost, PV currently costs about (€0.22-0.39/kWh) (see Appendix 3), depending on location. Almost all of this is comprised of capital costs, which have been falling and will continue to do so by as much as 50% within a few years, but this would still not make PV competitive with other technologies. In terms of intermittency, PV panels only generate power during daylight and there are no storage options, therefore cloudiness and seasonality influence the amount of power generated.

Concentrating solar power

The other option for solar electricity is CSP which makes use of reflectors to focus sunlight on a small area, in order to power a thermal electric plant. There are several technology variants, including fields of mirrors focusing sunlight on a tower, troughs of mirrors focusing sunlight on pipes, and parabolic dishes focusing sunlight on their apex. The first commercial plants in operation were built in the United States (410 MW) and Spain (100 MW). Globally, there are now more than 45 new CSP projects under development. These are scheduled to generate 5000 MW in North America, 2500 MW in Europe, more than 500 MW in North Africa and 2400 MW elsewhere[54].

CSP has two disadvantages relative to PV. First, it requires direct sunlight, meaning that no power is generated under cloudy skies. Hence, it only makes sense in arid or semi-arid climates with plenty of sunny weather. Second, like other thermal electric plants, the medium that is heated to power the turbine needs to be cooled. Water-cooling is the standard means, but this is problematic in arid inland regions. Alternatively, it is also possible to use air-cooling, at a small loss in efficiency.

However, CSP also has several advantages relative to PV. First, it costs less; estimates range from €0.135–0.218 per kWh depending on design and location (see Appendix 3) and it is expected that these costs will fall relatively quickly. Scenario studies suggest that CSP could achieve cost competitiveness with coal and gas between 2030-2045[35]. Second, CSP allows for short-term storage of the heated medium. With only a small loss in efficiency and no net increase in cost, it is possible to generate power overnight, providing base-load power.

Biomass

Biomass burning for electricity can be competitive with coal. Many existing plants make use of waste heat for district heating, raising the total efficiency to 85-90%[53]. When not combined with district heating, biomass is another dispatchable form of renewable power, since it relies on a storable fuel stock.

The main concern with biomass is the availability of fuel stock to sustain large scale burning; finding sufficient land and water to grow enough material could be problematic. In many parts of the world, growing crops dedicated to biomass production can lead to higher net carbon emissions than fossil fuels due to the emissions associated with land clearing[53]. There are also concerns about the impact on agriculture and food prices.

Other renewables

There are several other forms of renewable power that have yet to be demonstrated safely at a commercial scale. Of these, geothermal power has progressed the furthest, and in some places (such as Iceland) is commercially viable. Concerns about safety have come to light recently, however, after geothermal plants apparently triggered local earthquakes in Switzerland and Germany, and more study is needed.

Several different forms of tidal generators have been developed, with prototypes in operation in the UK, Canada, and Australia. Tidal power has the advantage of being completely predictable in its intermittency, but has the disadvantage of being economical only in locations with high tidal flows. Wave power is also being explored; the first commercial wave farm was recently installed in Portugal and funding has been secured for a second in the UK.

To a greater or lesser extent these technologies are at a relatively early stage of development and investor interest. They are not considered in any detail by this report.

Smart Grids and smart meters

Very few disagree that our electricity and energy systems need to be upgraded to meet 21st Century demands. The current grid architecture was developed around large scale carbon-based technologies, and in the future it will need to be able to service distributed generation, large-scale (and possibly intermittent) sources of renewable power and electrified transport. The ability of a Smart Grid to enable two-way communication between the consumers and producers of energy in key to this.

Investments are already being made to meet this challenge. The International Energy Agency (IEA) estimates that €500bn will be invested in transmission and distribution networks by 2030. We may also need an additional investment of approximately €180bn by 2030 in ICT alone to deliver Smart Grids. But what are the first priorities for investment? And do we have enough understanding of the opportunities and challenges to ensure that investments made today will deliver the Smart Grid vision?

According to one study[55], Smart Grid solutions could contribute more than 2Gt of CO_2e savings annually by 2020, mainly through enabling renewable power and optimising the power generation and transmission and distribution network. Smart Grid demonstration projects today are testing the full potential of the savings, which could be accelerated if a range of new services are developed.

3.4. Policy

3.4.1. Energy policy: Today's situation

Until recently, energy policy was an entirely national matter within the EU. National energy policies were more or less coordinated between Member States, but conflicts between policies were not uncommon. Examples are the proposed North Stream and South Stream gas pipelines; the North Stream is planned to connect Russia-Germany via a pipe in the Baltic Sea, which offended the bypassed eastern European countries, and the South Stream is planned to connect Russia-Austria/Italy, which is a direct rival project to the Commission's flagship project Nabucco.

Nonetheless, the experience gained through the development of an internal market and environmental and climate policies have resulted in the European Commission playing an increasingly important role in energy policy during the last 15 years. The most important legislations are the Market Liberalisation Directive in 2003[56] and the Renewables Directive in 2001[57] (see Section 3.5). With the entry into force of the Lisbon Treaty in late 2009, the competence for all areas with immediate relevance for the power system (i.e. internal market, environment, trans-European networks, and energy) is shared between the Union and the Member States.

Article 176A of the Lisbon Treaty states that "Union policy on energy shall aim, in a spirit of solidarity between Member States, to: (a) ensure the functioning of the energy market; (b) ensure security of energy supply in the Union; and (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (d) promote the interconnection of energy networks"[58]. It is, at the time of writing, not yet clear what the effects of the Lisbon Treaty on European policy will be, but the process of Europeanisation of the energy policy has been strengthened and it seems likely that the energy competences will remain and be strengthened at the European level.

The North African countries have a very limited cooperation in the energy field. This is primarily through the OPEC membership of Algeria and Libya, and the cooperation agreements with Morocco and Tunisia as transit countries for the gas export pipelines. There is also some coordination following the grid interconnections, but no clear tendencies to a regional energy or electricity policy harmonisation are visible.

Within the area of today's energy policy we now look in more detail at three particular areas: renewable generation targets, policy instruments for renewable electricity and energy subsidies and external costs.

Renewable generation targets

The EU prides itself as the world leader in climate protection. However, the EU15, which is a party to the Kyoto Protocol, is far from reaching its Kyoto target. Regardless of the target achievement, the EU is one of the largest emitters worldwide, both in absolute numbers and per capita, and the power sector is the largest single emitter in the EU[59].

EU climate policy prescribes a 20% reduction of greenhouse gas emissions by 2020 compared to 1990, a 20% more efficient use of energy and 20% renewable energy use. The main European policy instrument to reach the 2020 renewable energy target is the new Renewables Directive[60]. In this directive, national renewable *energy* targets are mandated depending on the resource availability and the capacity of each country. There are no renewable electricity targets at the European level: the allocation between electricity, heat and transport is for the Member States to decide. The directive allows the Member States to reach their targets jointly, or for one country to buy Guarantees of Origin from another country and use these for achieving its own target. It also allows EU states to produce or buy renewable electricity from third countries, for example North Africa, and use this to achieve its renewables target. Preconditions for this are that the renewable electricity is physically imported into the EU and the exports are additional to the export country's efforts to increase its share of renewables. Both of these mechanisms are therefore similar to the Joint Implementation (JI) and Clean Development Mechanism (CDM) mechanisms of the Kyoto Protocol.

Currently, the National Action Plans which set out how the Member States intend to reach their targets and whether they want to do this in cooperation with other EU or non-EU countries are being written. These must be submitted to the Commission by mid-2010.

The North African countries have also discovered renewables as an option for the future; however this is not primarily driven by climate protection. Instead, a key objective lies in energy security: the North African countries need to increase their generation capacity and reduce their dependency on fossil fuels for power generation, which is a major cause of the outflow of hard currency in Morocco and Tunisia. In the case of Algeria and Libya, an important driver would be to free domestic fossil fuel resources for the more profitable export, but it is not clear whether this is actually recognised by the government. Despite having good reasons to increase the shares of renewables, almost no renewable capacity has been installed in North Africa. It is only recently that most countries have set national renewables targets. These differ in range and level of ambition from the Moroccan target of 42% renewables in the power sector by 2020 to the Algerian target of 5% renewables by 2017 (see Table 1). The North African reactions to the possibilities of renewable electricity exports to Europe are cautiously positive but, at the time of writing, no substantial comments or commitments have been made by North African governments.

Table 1: Renewable electricity targets in North Africa[29]

Morocco	42% renewables in power mix by 2020 2 GW CSP by 2020 Integration into the European power system
Algeria	5% renewables in power mix by 2017 10% renewables in power mix by 2025 30% renewables in power mix by 2030 250 MW CSP, incentivised by a feed in tariff
Tunisia	4% renewables in power mix by 2012
Egypt	3% renewables in power mix by 2010 20% renewables in power mix by 2020, of which 12% wind
Libya	No data available

Policy instruments for renewable electricity

There are numerous efforts to stimulate the generation and use of renewable electricity throughout Europe. Currently, there are no significant policy instruments for the support of renewable electricity in place in North Africa, but these will be necessary to achieve the set targets.

All EU countries have priority grid access for renewables and, in most countries, renewable electricity has to be accepted by the grid operator as long as the system stability is guaranteed[61]. More importantly, all Member States have support schemes for renewable electricity. These efforts are more or less uncoordinated at a European level and differ significantly between countries. In the process before the adoption of the Renewables Directive, the Commission tried to gather all national efforts under a European tradable green certificate scheme, but failed due to strong resistance in the Member States and the European Parliament[62-63]. It seems very likely, and in the words of the Commission "more appropriate", that most support schemes will remain national for a foreseeable future, although the Renewables Directive gives provision for Member States to reach their renewables targets jointly. A joint support scheme would be one way to do so[60, 64].

Currently, there are 18 EU countries with feed-in tariffs, five countries with tradable green certificates, one country that has both feed-in tariffs and tradable green certificates, and three countries that support renewable electricity with tax reductions[61, 65]. The efficiency and effectiveness of the support schemes differ greatly between countries, with feed-in tariffs generally considered to be the most effective, as they have led to the largest capacity increases in Europe, and are the most efficient on a €/kWh basis[24]. In most EU countries only the amount of renewable electricity generated is rewarded, regardless of when and where the electricity is fed into the grid. In some countries, like Germany, discussions about how to reward power stations providing dispatchable load have begun ("Kombikraftwerksbonus", or virtual power plant bonus[66]), but there has been limited progress in the inclusion of such regulations into the support schemes. Virtual power plants are in the pilot phase and a number of concepts are being tested throughout Europe[67].

The EU ETS is the central European climate policy instrument which seeks to limit emissions in key sectors and put a price on carbon, thereby encouraging investment in renewables and other low carbon technology, by making the carbon-emitting technologies more expensive. In the initial, 'learning by doing' allocation period (2005-2007), the cap was set too high and so had very limited effect on European carbon emissions, with the price falling to almost zero at the final year of the period, as the market was flooded with unused EU Allowances (EUAs). In the second trading period (2008-2012), the design of the scheme has been refined and more ambitious targets set. The carbon price has recovered and currently fluctuates between €10/t and €15/t [68].

The EU ETS has demonstrably contributed to a reduction in European emissions and has set a price for carbon, which has provided an additional incentive for investment in renewables, particularly in the second period. However uncertainty over future policy, particularly at an international level, has undermined confidence in carbon prices and weakened the investment incentive for long-lived assets.

Energy subsidies and external costs

Although typically based on market principles, the price for electricity in most countries in the world is impacted by a range of explicit and implicit subsidies and rebates and other market interventions which distort the market. The nuclear industry in particular benefits from the State acting as an insurer of the last resort, providing effective cover that might not otherwise be available in the insurance market[69], whilst coal fired generation typically does not currently bear the full environmental cost of its activities. Internalising these external costs would increase the costs of nuclear and coal fired generation and make renewables more economically attractive[70].

The power market in Europe also reflects the ownership history of the sector, with a number of former national monopolies still dominant and a legacy of very large, old power stations in many countries, and the structure of regulation in national markets. Power prices are generally low relative to GDP and so energy poverty is only a marginal problem in most countries.

In North Africa, the scale of direct subsidies of electricity consumption is much greater, disguising the true costs of electricity generation in this area. Electricity production of any kind in North Africa is generally far from economically viable, yet the large electricity subsidies lead to very low electricity prices and make electricity affordable to large parts of the population, which eases the significant problem of energy poverty. Tunisia and Morocco, which do not have large fossil resources, have relatively lower energy subsidies compared to other countries in the region, accounting for approximately 2% of GDP. Algeria, Tunisia and Egypt have already started programmes to reduce subsidies and adjust the electricity prices to international levels. All governments in the region acknowledge that greater use of renewable electricity could help to reduce subsidies in the long run[29, 71].

Maintaining decarbonisation momentum

Many worry that the failure to sign a legally binding global agreement on reducing greenhouse gas emissions at the 2009 Climate Summit in Copenhagen will delay or dilute efforts to decarbonise. While a binding agreement would undoubtedly have provided greater clarity, much of the momentum for decarbonisation is, in any case, coming from national and regional initiatives rather than globally. Continuing delays at a global level may even present opportunities for better engagement, coordination and success at a regional level, if the political will is there.

The most recent energy modelling results associated with the Intergovernmental Panel on Climate Change (IPCC) suggest that, to stand a chance of keeping global warming below a 2°C average limit, global CO_2 emissions need to peak, and then start falling, before 2020[35]. We therefore need to move forward quickly with decarbonising our major economies. The power generation sector can play a major part - CO_2 emissions resulting from fossil fuel combustion in the power sector have been estimated to account for almost 26% of anthropogenic GHG emissions. This provides us with an opportunity to take specific action in an area that is a significant contributor to the problem.

3.4.2. Tomorrow's vision: A European energy policy and phase-out of subsidies

In our 2050 vision, both the national energy policy and the energy foreign policy of EU countries have been Europeanised. In addition, the European and North African energy policies have been aligned and there is close cooperation on electricity policy. Due to the synchronous grid operation of the North African and EU power grids, the EU and North African TSOs collaborate closely, especially on grid planning and operation. Since both the market and the transmission grids are operated and optimised internationally, there is one governing body regulating the EU-NA grids, as well as future expansions or structure changes.

We would envisage that the decline in fossil energy trade, due to reduced need for fossil energy for power, may also have affected North African countries, especially Algeria and Libya, which could experience significantly reduced export income. Through proactive policy action, the economic impact of any decline in oil and gas export revenues can be managed, partly by new income streams coming from the export of renewable electricity, but mainly by a general diversification of the economy. Nonetheless, it is possible that the effects of the diminishing fossil energy revenues could still be felt in parts of the region in 2050.

The 2050 vision will, hopefully, have been reached through a stable and predictable policy framework with a combination of regulations and obligations, as well as financial incentives and support mechanisms along the way. However, by 2050, we would expect all financial support mechanisms to have been phased out and all power technologies that are in use able to be operated on their own economic and technical merit, depending on their value to the system as well as their production costs.

In our vision, it won't just be technologies with the lowest production costs that are used. More expensive technologies with other beneficial characteristics are also valued. Intermittent sources may have very low levelised electricity costs, but will to some degree need a dispatchable reserve. Such dispatchable power plants may be more expensive per kWh due to the higher value of the dispatchable electricity but have a valuable role to play.

We would envisage that the EU ETS and the price of carbon no longer play a role for the power sector as it is completely carbon neutral. On the path to 2050, however, the EU ETS will have played a key role in the decarbonisation of the power sector, by encouraging investment in renewables and discouraging new fossil-fired power generation early on through increasingly stringent caps and, over time, pushing existing fossil-fired plants from the market.

3.5. Market

3.5.1. Power market structure: Today's situation

European power market

The European power market is in a transformation phase which begun in the late 1990s when the first liberalisation and internal market directives were issued. The last decade has been characterised by ongoing debates about how to improve the functioning of the liberalised market, the need to unbundle the national champions and market unification. The policy support for renewable electricity and emissions trading are two other major issues in the power sector and, despite the settling of some issues (e.g. unbundling and the Renewables Directive), uncertainty remains about the long-term power market design.

The European electricity market is, despite its formal unification, a fragmented market consisting of a large number of national power markets with different levels of interconnections to neighbouring countries, as well as one coupled market (France-Benelux). Only the Nordic market has been successfully unified and this was mainly due to the already strong interconnections and the tradition of trust between the Nordic states. The Nordic market is currently the only international power market in the world[72-73]. The trade between the EU countries is increasing, but this still comprises only 10% of the electricity consumed in the EU[13-14].

All European markets are formally completely liberalised[56], but due to market fragmentation and weak interconnections, the national market leaders typically still dominate their former monopoly markets. In 15 EU Member States, the three largest producers control more than 90% of the wholesale market[14]. Only the UK, the Netherlands, Austria, Hungary, Poland and the Nordic region (except Denmark) are considered moderately concentrated markets; all other national markets are highly or very highly concentrated (see Figure 6).

Competition in the European power markets is therefore still weak. Only 11 Member States have implemented the Market Liberalisation Directive of 2003, many have still not done so and numerous infringement procedures have taken place[74]. All Member States have fulfilled the weak transmission system operators (TSO) unbundling requirements, but only 15 of the 41 European TSOs are fully separated from production and retail. More than half of the Member States allow the distribution system operators (DSOs) to remain vertically integrated[74]. In most respects, electricity markets and policy are still a national rather than an European affair, but the Europeanisation process has started.

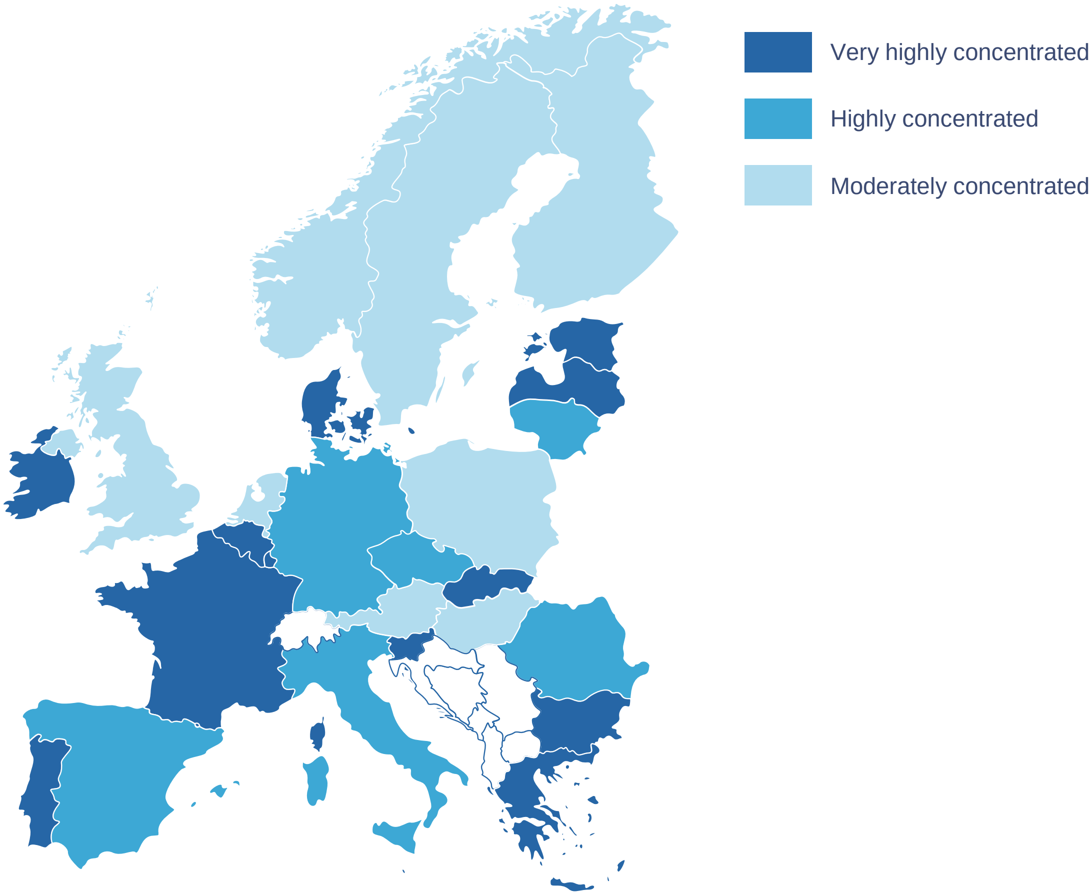


Figure 6: Market concentration in the European (EU27) national power markets[74]

Pricing

The power market as it has existed since market liberalisation in the 1990s is built around the task of matching supply to demand in a way that takes advantage of the cost structures of today's main technologies. Hydro and nuclear have the highest capital costs, but also the lowest marginal costs, while gas has the lowest capital costs, but very high fuel costs. Power suppliers submit bids on the spot market at prices reflecting their marginal costs. The system operator then accepts bids in the "merit order" of prices. The price that all suppliers receive is fixed by the most expensive bid accepted, which changes according to demand. The high wholesale price during peak load periods, a result of the heterogeneity of cost structures, and the even higher price during scarcity periods make it possible for operators to cover their fixed costs[75]. Thus, for normal, non-control capacity, the marginal cost of the last unit needed to cover demand and the amount of traded energy is the base for the pricing. Capacity, dispatchability or other features which may have a value to the power system are not considered in the current pricing system.

North African power markets

The North African markets are not yet liberalised, although there is some work underway in this direction in most countries, such as unbundling and third-party access to the grid. It remains to see how far these first liberalisation steps will go, as all governments seem rather reluctant to loosen the grip on the power sectors. All markets are completely dominated by national, state-controlled and vertically integrated utilities. The states also control the pricing through strong subsidies on electricity consumption, which is a serious impediment on the construction of new capacity[71]. All five national grids and markets are interconnected, but intra-North African electricity trade is almost non-existent: the sum of all exports and imports between the North African countries in 2006 was 1 TWh[4].

3.5.2. Tomorrow's vision: A unified European-North African power market

In our 2050 vision, the European internal power market has been completely unified and it has been united with the North African countries. The completion of the EU-NA power market will have been accomplished through the unification of regional markets, which will have grown organically over time. This market structure, together with the dense and efficient HVAC and HVDC power grids, would enable free and efficient electricity trade within Europe and between Europe and its southern neighbours.

To ensure that enough generation capacity is available at all times, an additional market which recognises and rewards dispatchability will have been introduced alongside the traditional power market. Thus, both the system value of the electricity and the value of capacity and dispatchability are made visible and are rewarded.

By 2050, all power companies will have been vertically unbundled to ensure a fair and independent grid operation. The grids are under strict control and are operated, planned and optimised in a European-North African perspective. Due to the internationalisation of the power market and a large share of decentralised generation in Europe, no single producer or retailer can act as price-setter. Companies with a too dominant position even in a pan-European-North African market have been horizontally unbundled and split into smaller entities.

Nonetheless, we would envisage a number of large European power companies having significant, but not market-controlling, shares of generation and wholesale supply within Europe and North Africa, and a number of North African companies dominating the export trade to Europe. The increased number of level players in the market, together with consequent and transparent market regulations, ensures the proper functioning, without distortions and corruption, of the entire EU-NA power market, including the markets for new power plant and infrastructure capacity.

3.6. Costs

There are two areas that should be looked at when considering costs: the actual costs of generating renewable electricity, and the economic contribution of renewable energy. Both of these are considered when looking at today's situation and tomorrow's vision.

3.6.1. Renewable electricity costs: Today's situation

Renewable electricity costs

Under current market conditions renewable electricity is generally not economically competitive with fossil fuelled power, or with existing nuclear power. Direct and indirect subsidies of fossil and nuclear power, as well as support schemes for renewable power exist in parallel, which makes a direct cost comparison difficult. Existing and depreciated large scale hydro power stations are the cheapest renewable generation option. Modern wind power at very good sites is nearing being cost competitive with fossil fuels, but is still on average more expensive than the conventional generation options. Government incentives, such as feed-in tariffs, are currently the main drivers for investment in renewable electricity. However, the gap between renewables and conventional power is decreasing and is expected to continue to decrease, both due to technological development of the still immature renewable technologies and due to increasing prices for fossil fuels and carbon emissions.

The costs of generating power depend on many factors, some of which are project or investor specific. The fuel prices for fossil power plants are largely exogenously given, as are the largest parts of the investment costs for all generation technologies. Economic parameters, such as discount rate, rate of return and other project specific factors, are hard to generalise to make a fair comparison for all technologies. Nonetheless, many studies seek to do exactly that. Based on these studies, and with appropriate caveats in relation to uncertainty, we make a comparison of generalised cost estimates based on the levelised cost of electricity method (LCOE), or in the case of HVDC transmission, levelised cost of transmission. Data and details on assumptions for these calculations are available in Appendix 4. The results of these calculations are presented in Figure 7.

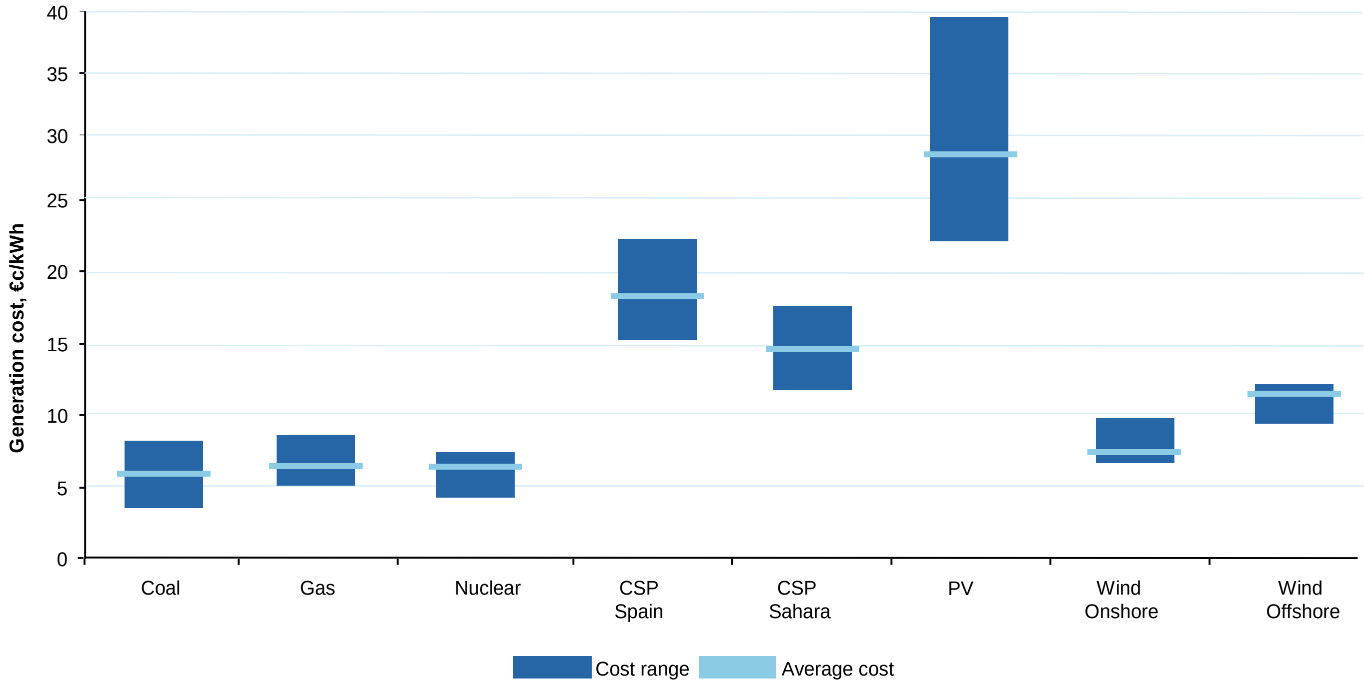


Figure 7: Typical levelised costs of electricity generation[39, 79-85]

For the costs of transmission, the literature is not very broad and there is some circular referencing between sources. A good estimate is that HVDC transmission costs over 2200 km (of which 200 km is subsea) lie in the range of 1-3.5 €c/kWh, with a higher probability for the lower end of the range[5, 11, 76-77]. For a fair comparison of costs to European consumers, these transmission costs have to be added to the LCOE of technologies deployed in North Africa; for North African consumers, the undistorted LCOE applies.

Clearly, the conventional technologies are cheaper than CSP and in most cases, cheaper than wind power, even including the carbon price (at today's levels). If we add the costs of HVDC transmission to the cost of CSP in Sahara we see that it would be cheaper to build a CSP power plant in the Sahara with a 1000 km HVDC line to Spain than to build the CSP plant directly in Spain.

Most technologies get cheaper with time, as experience in construction and design, as well as economies of scale, improve efficiency in production and deployment. This applies to most electricity technologies as well, with the possible exception of nuclear power, which has tended to become more expensive with time[78]. These learning effects have strongly reduced the costs of onshore wind power over the last two decades to levels where it is almost competitive with fossil power. At good sites in Europe and North Africa, wind power may already be the cheapest option for new capacity.

These learning effects were derived primarily from significant early investments, much of it in Europe, normally incentivised by stable policy frameworks. The same type of effects can be observed in PV, although this technology is still much more expensive than all conventional technologies, wind power and CSP. It can be expected that CSP will experience cost reductions of 5-15% per doubling of installed capacity[35, 78]. Growing CSP capacity to 60 GW, which is half of the global wind power capacity of 2008, would then reduce the installation costs by up to 60% compared to today. Considering the sustained and rather stable annual growth rates of 20-30% (wind), 10-20% (biomass) and 50-100% (PV)[27], it is very likely that this cost decrease will continue for all renewable technologies. This means that, although the costs for CSP are higher than for conventional technologies and wind power today, it could well become the cheapest generation option in 10-20 years (see Chapter 5.2).

Economic contribution of renewable energy

The support for renewable power technologies has not only caused strong cost reductions, but it has also led to the creation of increasingly strong supply chains for a broad-scale expansion of renewables. In some countries the supply chains for the renewables industry are significant employers: in Germany alone, some 85 000 people work in the wind power industry, 96 000 work with biomass energy and 74 000 people work with solar energy[65]. No robust numbers for the entire EU are available, but it can be expected that the European renewable job market is at least twice as large as the German market.

The rapid growth and clear direction of the European energy and climate policies create strong incentives for expanding the supply chains. Nonetheless, bottlenecks may appear. For example supply constraints for wind power have led to a significant increase in costs and waiting times of several years between ordering and completing a wind farm[79]. The creation of new green jobs in the renewables industry is gaining increasing attention in policy debates over future support for renewables and the emergence of a strong domestic renewables sector is often seen as a key objective in the intra-European competition for qualified and sustainable jobs[80].

3.6.2. Tomorrow's vision: Cost competitive renewable electricity

Renewable electricity costs

We would envisage that all renewable technologies in operation in 2050 will have experienced significant cost reductions and be cost competitive, acknowledging not only the production cost but also the system value of both the energy and the capacity. In this way it won't just be technologies with the lowest production costs that get used. More expensive technologies with other beneficial characteristics such as dispatchability are also valued.

In 2050, our vision assumes that almost that all citizens in both North Africa and Europe have access to the power grid and the electricity market, due to the implementation of consistent electrification programmes, especially in North Africa. Energy poverty is no longer an issue. We would anticipate that the average electricity price in North Africa is at a much lower level compared to GDP than today, making non-subsidised electricity affordable to the entire population. The European average electricity price in comparison to GDP is at the same or at a lower level as today.

Due to the fluctuating nature of some of the renewable electricity sources, we would expect price levels to be volatile in the short term, over hours or days. However, in the long term the electricity price would be much less volatile than today because it would not be dependent on the price of fuel imports in the world energy market. The price elasticity would clearly be higher than today due to the increased time resolution in electricity pricing to consumers. Short-term price volatility will have become an important system feature and a trigger for demand responses at times with short electricity production. This, in turn, makes shifted or reduced loads one of the keys to balancing the system. Electromobility, in the form of plug-in hybrid vehicles, offers some additional shiftable load.

2050 economic contribution of renewable electricity

Over time, the traditional power sector will have transformed into a renewable power sector with a large number of the same actors as today, both in generation, retail and in the supply chains, but also with many newly emerged renewable power companies. The supply chains for all renewable technologies will have been built up over many years and constitute a mature and strong industry. In 2050, after the transformation phase to a renewable power system, the producers of the grid and renewable power plant infrastructure will have consolidated and have for some years shown decreasing turnovers and declining numbers of employees in the European and North African markets. But the experience of the transformation in these markets will give them a springboard to become important worldwide players as other major markets make similar moves to renewable electricity. Thus, the renewable power companies and industry will remain an important sector, securing a large amount of sustainable jobs due to the relatively short reinvestment cycles of many renewable power technologies. The supply chains will not only have been built up in Europe but also in North Africa, making the renewable power sector an important contributor to the creation of new, long-term employment of skilled workers in North Africa.

A summary of the 2010 starting point

- The power systems of Europe are dominated by fossil fuel (55%) and nuclear (30%) electricity. The North African power systems are made up of 67% gas and 20% oil power.
- By far the largest part of the renewable electricity comes from old hydro power stations. There has been some expansion of renewable energy, mainly onshore wind and biomass power, in Europe over the last 10 years but this has been focused on a few EU15 countries and the overall growth has been modest.
- The European grid is split into 5 asynchronous blocks connected with a few HVDC interconnections. The North African grid consists of two synchronous blocks. There is significant grid congestion, especially at national borders.
- The European power market is fragmented, consisting of a large number of national markets, which are dominated by a few very large companies. Despite the trend towards closer cooperation between markets, the Nordic market remains the only international power market. The pricing at the European power exchanges is based on marginal costs. The North African markets are strictly national and strongly regulated.
- Most countries are self-sufficient in electricity, but very dependent on fuel imports. Less than half of the European power plant fuel comes from domestic EU sources. For Algeria and Libya, the situation is reversed: these economies are largely based on income from the export of oil and gas.
- Electricity policy is still largely a national matter, rather than a European one. With the Lisbon Treaty, the EU ETS and the Renewables Directive, the European dimension has gained importance, but the impact of this is not yet clear. All renewable electricity support schemes and other renewables policy implementation instruments are still strictly national. National renewables targets are emerging in North Africa.
- Renewable electricity is still more expensive than conventional power, with the exception of wind power at very good sites, in part due to explicit and implicit subsidies for fossil and nuclear power. The renewables expansion in Europe is driven by national support schemes. Power price subsidies in North Africa are a major expenditure for most governments and strongly distort the market for new renewable power plants.
- A renewable energy industry is emerging in Europe, and is rapidly gaining importance as an employer.

4.

Getting there: The 2050 roadmap

“The transformation of the power sector is inevitable but a successful transformation requires clarity, transparency and long term policies. The Global e-Sustainability Initiative (GeSI) welcomes this report as it suggests a possible, sound and sustainable pathway to a zero carbon power sector, one of the building blocks for long-term economic growth and competitiveness.”

Luis Neves

Chair GeSI
Vice President Corporate Responsibility, Deutsche Telekom AG

4. Getting there: The 2050 roadmap

In the previous chapter, we discussed the current situation, constraints and challenges facing the European and North African power systems and described a vision of a 100% renewable energy power for 2050. Will it be possible to make the journey from 2010 to this 2050 vision? Such a journey presents a formidable challenge for government and industry in terms of complexity, cost and duration. What is needed, therefore, is a way in which the complexity and risk can be reduced so that measurable and manageable actions can be proposed and achieved over time. The roadmap that we present in this chapter seeks to do this.

It is important to note that the roadmap is only one of a number of ways in which a 2050 vision could be achieved. All dates and timings are estimated and further work will be required to develop the plans and identify the detailed activities needed to take this forward.

The roadmap is based on a three part approach:

- **EU-NA power market model:** Today's power sector in Europe and North Africa is complex. Decades of investment in generation and transmission infrastructure aimed at supporting economic development have created intricate supply chains and policy landscapes. What is needed is a simpler way of understanding (i) the key drivers and influences that shape the organisations in the industry and (ii) the sector itself. This report proposes a simplified power market model that comprises nine areas of interaction.

- **Power system model priority areas:** Within these nine areas of interaction in the model it is possible to identify four key enabling areas that will drive any transformation of the renewables market and five supporting areas. The enabling areas will be pivotal to achieving the 2050 transition. They are: government policy, market structure, investment and finance, and infrastructure and planning.

- **Gap analysis**: The roadmap sets out activities and dependencies for these four enabling areas in the period to 2050. The current state of the EU-NA power market has been taken as our starting point and the 2050 vision as our desired outcome. By comparing these two states we have identified the 'gap' or activities that need to be completed in the intervening years. The gap analysis has also highlighted other areas of activity and further research that will be required for success.

4.1. The Europe and North Africa power system model

This report uses a simplified market model to understand the main components and drivers for the power market in EU-NA. We recognise that there are currently significant differences in the set up and operation of the European and North African energy markets. However, in order to make the analysis clear, the model identifies nine separate areas of interaction: government policy; market structure; investment and finance; infrastructure and planning; technology and R&D; supply chains; generation capacity; grid capacity; and demand, as illustrated in Figure 8. We focus on the first four of these of these, as these are key enabling drivers which spur the development of the others and of targets set across the model.

By using such a model, we hope to view the challenges and opportunities in a more holistic manner and to identify how the linkages and interdependencies between areas could help to drive a wider transformation across the renewables area in the short and long term. In creating a detailed roadmap based on the above approach, we seek to start with what is in place today, work with the existing technology and initiatives and deliver a vision of a 2050 power sector that is much better placed to address the climate and energy challenges that we face.

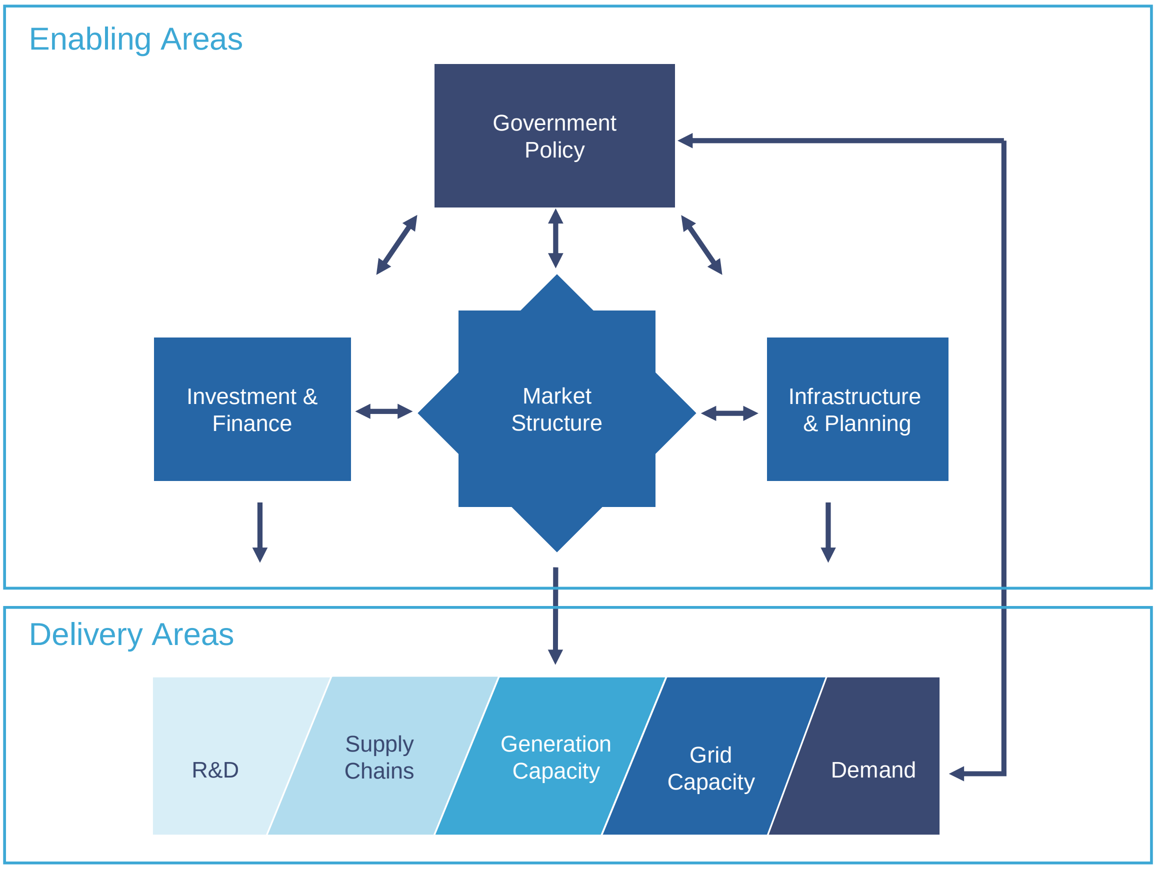


Figure 8: The European and North African power system model

4.1.1. Enabling areas

Government policy: This has been placed at the apex of the market model as it is often the catalyst that shapes the market, stimulates business activity and, if introduced appropriately, will support long term behavioural and structural changes across an industry or sector. For the purposes of this report, this area includes legislation, policy and other instruments that governments put in place at a national or regional level to promote renewable energy. The report assesses at a high level what is in place currently across EU-NA and how this needs to evolve to achieve the 2050 end state.

Investment and finance: Strongly influenced by government policy, the investment and finance community provides the bulk of the financing needed to deliver new renewable energy generation and transmission projects. This area considers investor concerns and requirements in particular in relation to the certainty, transparency and longevity of government incentives.

Market structure: This area looks at the organisations involved in the generation and transmission of electricity, the regulation that is in place, the way in which electricity is bought and sold and the way in which national markets are connected regionally.

Infrastructure and planning: This area is concerned with the high level regional planning of physical assets and other infrastructure that supports the generation and transmission of power. It considers location, interconnection and power mix and the interaction between HVAC and HVDC that will be needed to allow a power market heavily dependent on renewables to operate.

4.1.2. Delivery areas

R&D: All forms of renewables still have considerable scope for further improvements in the design, cost, efficiency etc of the technology and configuration. There is also still some element of technology shake-out that is anticipated in the industry in the coming years. Substantial investment in R&D will be needed to drive this, along with a reduction in overall costs to a point where renewables achieve cost parity with other sources of energy.

Supply chains: Scaling up construction of new renewable generation and transmission infrastructure will only be possible if there is an effective supply chain in place. Production of most of the components for renewable generation infrastructure currently happens in western Europe. Over time, as more projects are developed, this will need to expand significantly as well as move to new locations. This will only happen, though, if the areas above create a favourable environment that supports the business case for this.

Generation capacity: This area is concerned with the details of the local generation infrastructure. Currently this is largely based on fossil fuels and nuclear and based on the task of precisely matching supply to demand to take advantage of the cost structures of today's technologies. Over time these assets will age and need to be replaced. This requires close planning and management.

Grid capacity: This area is concerned with the details of the local transmission infrastructure capacity. Europe and North Africa today have grid infrastructure that is suited to today's generation infrastructure. With increasing renewables will come a need to substantially upgrade existing infrastructure, improve the ICT architecture, increase the geographical scale at which the grid is managed, and improve the management of demand for electricity. This will also require close planning and management as well as coordination with generation capacity planning.

Demand: This area refers to activities that are undertaken to understand and manage demand for electricity. Energy efficiency and demand management will play an important role in dictating future energy requirements that will in turn shape the investment and infrastructure plans for transmission and generation.

4.2. Roadmap planning horizons

The analysis has been broken down into three planning horizons consisting of seven milestones, as shown in Figure 8. These are:

Short term:	Dec 2010	Medium term:	2020	Long term:	2040
	2012		2030		2050
	2015				

These milestones have been chosen based on an assessment of when it is likely that activities can or need to be completed by e.g. because of existing targets or otherwise, other considerations driven by prevailing conditions, and with regard to what is on the critical path to achieve the 2050 outcome. Taken together, the milestones help to achieve the necessary transformation in government policy, market structure, investment and infrastructure to achieve the 2050 end state.

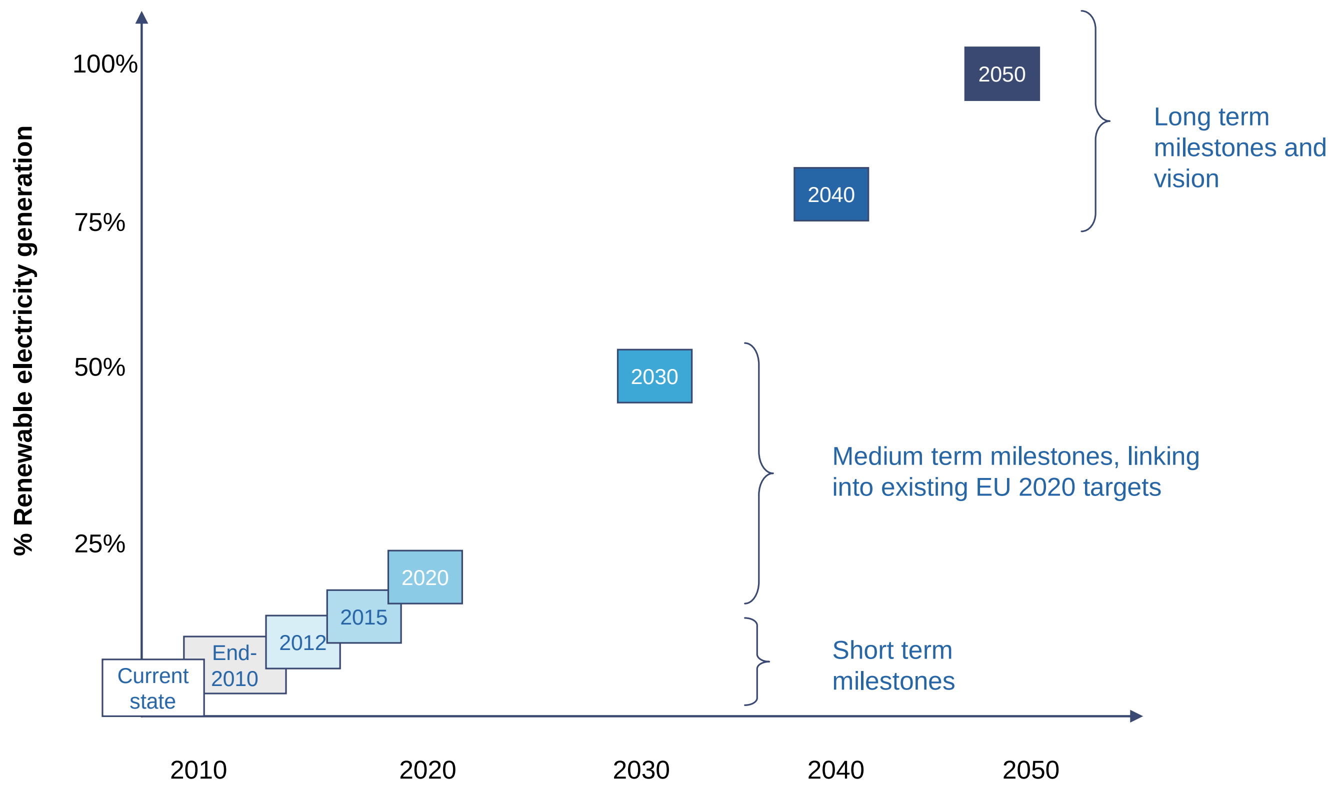


Figure 9: Roadmap planning milestones for the transformation of the power sector

The roadmap context

We have designed the roadmap and written this report to be consistent with the current climate change and energy system thinking. Three recent studies provide the context for the roadmap's focus on a 100% renewable EU-NA scenario as well as current development on the ground such as the Desertec Industrial Initiative (DII) and Seatec (North Sea Super Grid).

The ADAM project: From 2006 to 2009, 150 researchers at twenty-four of the leading European research institutes and universities worked together on the ADAM project, a flagship research initiative of the European Commission in the area of integrated climate policy. Many of the key insights in the synthesis book from the ADAM project, Making Climate Change Work for Us, are reflected in this report[81]. A key insight of the ADAM project, for example, is that it may in fact be counter-productive to search for the low hanging fruit of small, inexpensive emissions reduction options. Instead, what is needed is for policy makers to lay the framework now for a complete transition to decarbonised energy, to "build a ladder" to pick the energy system tree free of all of its CO_2 emissions sources, replacing them with renewables and non-emitting alternatives.

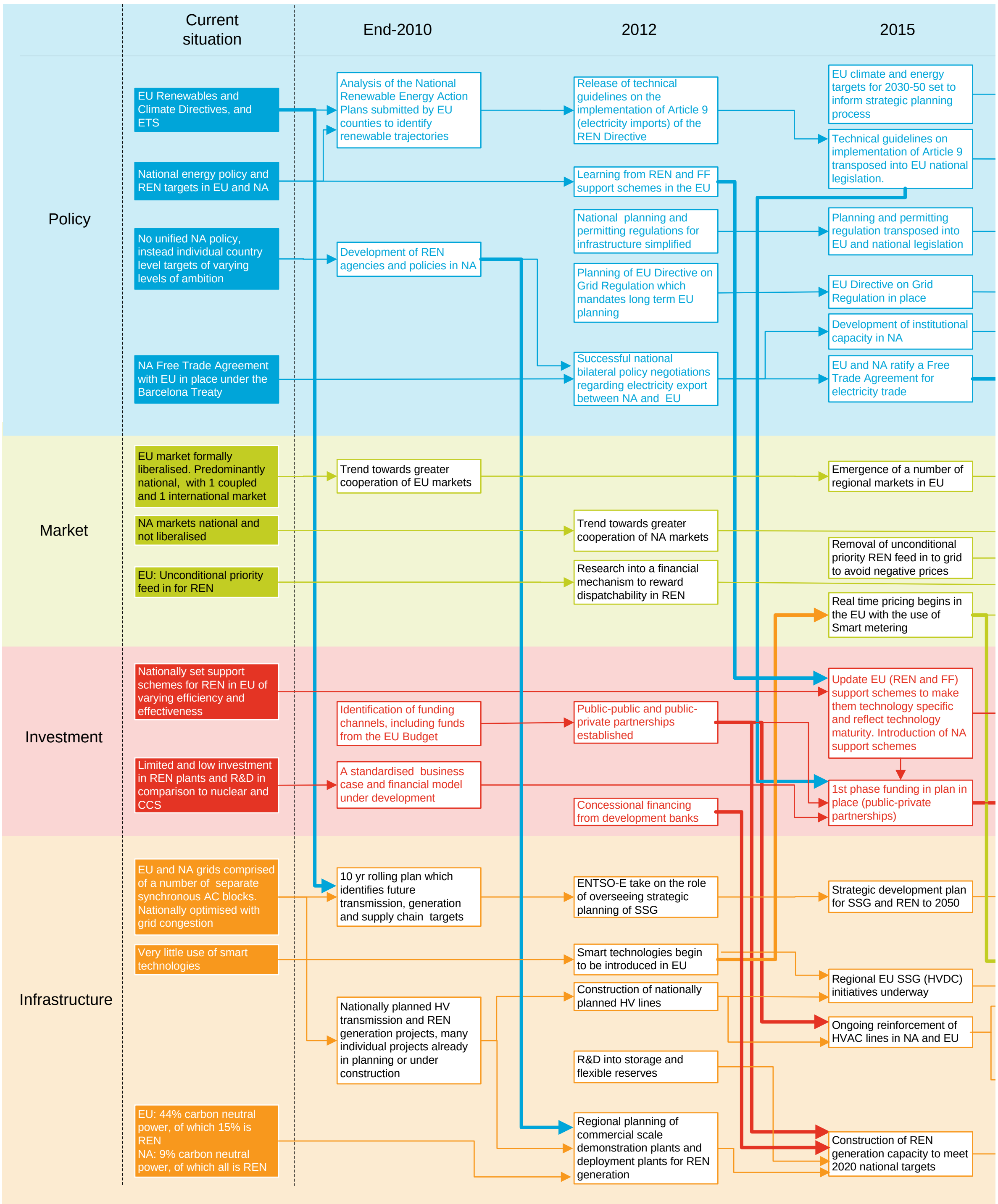
Sustainable energy – without the hot air[2]: David MacKay is Chief Scientific Advisor to the UK's government's Department of Energy and Climate Change. MacKay examined whether there is enough land and continental shelf area in the UK, and in Europe more generally, to satisfy current energy demand entirely with today's renewable energy technologies. He concluded that technically there is, but realistically there is not, given public opposition to filling every available space with windmills and solar panels. He suggests that, for Europe to eliminate its CO_2 emissions, it would have to scale up nuclear power production, or rely on a great deal of CCS, or import significant amounts of solar power from North Africa. In line with our 'what if' approach, the roadmap is based on a scenario in which imports of renewable power from North Africa contributes a major share.

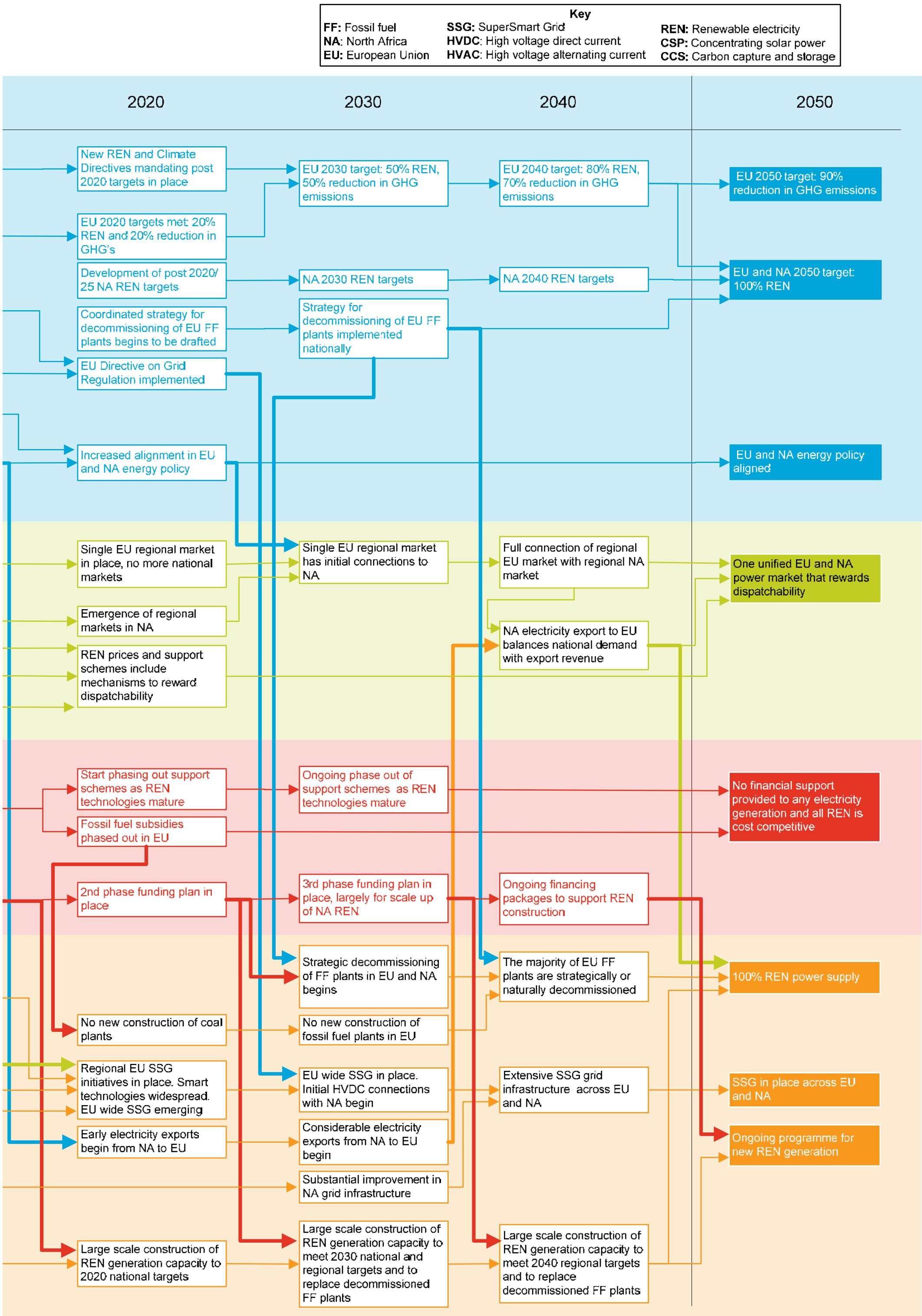
Low emissions scenario modelling: In its 2007 Assessment Report, the IPCC suggested that, to limit global warming to 2°C, it would be necessary to stabilise atmospheric concentrations of CO_2 at 450 ppm. They suggested this could be achieved with a 50% reduction of global emissions by 2050, including an 80% reduction in currently high emitting developed regions, such as Europe[82]. Since then, a number of studies have shown that 450 ppm may, in fact, be too high. Beginning with the ADAM project[81], and continuing with the current work commissioned by the IPCC for its next assessment report[35], modellers from the Dutch national environmental assessment agency have examined the feasibility of achieving more rapid cuts in emissions. Their conclusion: it is possible, even considering the lifetime of capital infrastructure now in place; it will not be expensive, having a total effect on annual economic growth rates of less than 0.1%; it will require a major shift in the patterns of new investment in the energy system, beginning by 2013. Identifying the policy framework needed to bring about this change of behaviour on the part of private investors is a key focus of this report.

4.3. Introducing the roadmap

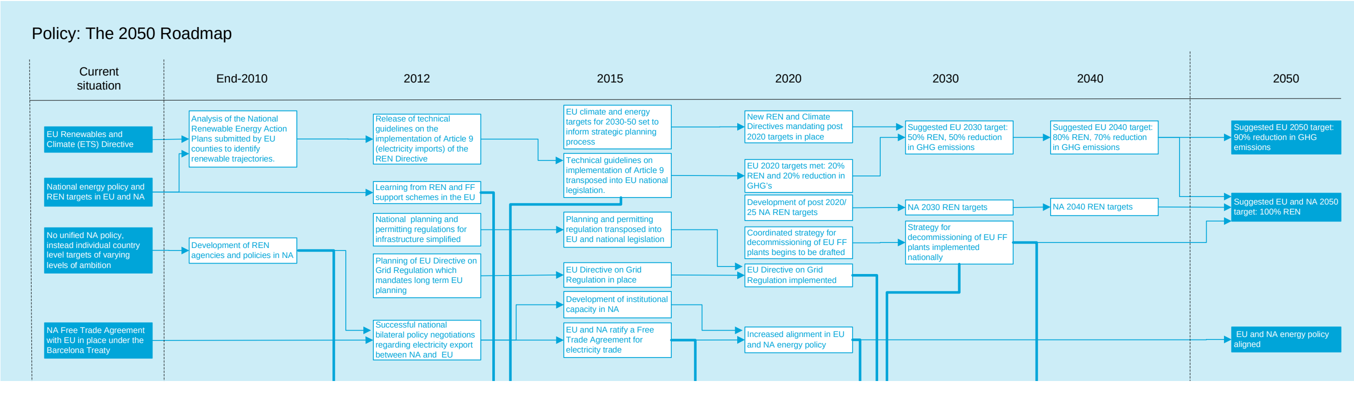
To achieve our 2050 vision from the complex power system of today, there is no singular definitive or correct route, but rather a number of differing but complementary paths. The schematic presented in Figure 10 illustrates one such roadmap. It is based on our assessment of the milestones required to achieve the vision, but should not be considered as the only way to do so. It considers the activities required in each of the four enabling areas: policy, market, investment and infrastructure. The interdependencies between these themes are critical to achieving the vision and are shown in bold. Milestones are stated for either the Europe, North Africa or where no specific region is given the milestone applies to both.

Figure 10: A roadmap to 2050




Key
FF: Fossil fuel
NA: North Africa
EU: European Union
SSG: SuperSmart Grid
HVDC: High voltage direct current
HVAC: High voltage alternating current
REN: Renewable electricity
CSP: Concentrating solar power
CCS: Carbon capture and storage
2020
2030
2040
2050
New REN and Climate Directives mandating post 2020 targets in place
EU 2020 targets met: 20% REN and 20% reduction in GHG's
Development of post 2020/25 NA REN targets
Coordinated strategy for decommissioning of EU FF plants begins to be drafted
EU Directive on Grid Regulation implemented
Increased alignment in EU and NA energy policy
EU 2030 target: 50% REN, 50% reduction in GHG emissions
NA 2030 REN targets
Strategy for decommissioning of EU FF plants implemented nationally
EU 2040 target: 80% REN, 70% reduction in GHG emissions
NA 2040 REN targets
EU 2050 target: 90% reduction in GHG emissions
EU and NA 2050 target: 100% REN
EU and NA energy policy aligned
Single EU regional market in place, no more national markets
Emergence of regional markets in NA
REN prices and support schemes include mechanisms to reward dispatchability
Single EU regional market has initial connections to NA
Full connection of regional EU market with regional NA market
NA electricity export to EU balances national demand with export revenue
One unified EU and NA power market that rewards dispatchability
Start phasing out support schemes as REN technologies mature
Fossil fuel subsidies phased out in EU
2nd phase funding plan in place
Ongoing phase out of support schemes as REN technologies mature
3rd phase funding plan in place, largely for scale up of NA REN
Ongoing financing packages to support REN construction
No financial support provided to any electricity generation and all REN is cost competitive
Strategic decommissioning of FF plants in EU and NA begins
The majority of EU FF plants are strategically or naturally decommissioned
100% REN power supply
No new construction of coal plants
No new construction of fossil fuel plants in EU
Regional EU SSG initiatives in place. Smart technologies widespread. EU wide SSG emerging
EU wide SSG in place. Initial HVDC connections with NA begin
Extensive SSG grid infrastructure across EU and NA
SSG in place across EU and NA
Early electricity exports begin from NA to EU
Considerable electricity exports from NA to EU begin
Substantial improvement in NA grid infrastructure
Ongoing programme for new REN generation
Large scale construction of REN generation capacity to 2020 national targets
Large scale construction of REN generation capacity to meet 2030 national and regional targets and to replace decommissioned FF plants
Large scale construction of REN generation capacity to meet 2040 regional targets and to replace decommissioned FF plants

4.4. Roadmap enabling area 1: Policy



4.4.1. Introduction

The model in this report places government policy at the apex of the power sector market model. This is because it has the ability to encourage or discourage large scale investments, activities and developments in an industry. It has also been used to support new and emerging technologies, especially those found in the renewable and low carbon industry and those in early stages of development, to compete effectively with established technologies. Governments around the world interested in developing a renewables industry have generally responded by providing policy schemes that broadly fall into two categories. 'Push policies' stimulate a specific activity, whilst 'pull policies' obligate an activity. Often, a mixture of incentives will be used and this offers governments both challenges and opportunities. Designing a coherent and best-practice suite of renewable energy policies will encourage innovation and investment across a range of technologies. However, if mis-designed, an entire industry can lie dormant for years.

A good example is the US government support that was provided in the early 1980s. This led to the development and installation of 354 MW of CSP capacity in California. When the US government support was stopped in the late 1980's, it led to a complete cessation of project development activities, highlighting the link between continued support and continued activity. The 15 years of inactivity in the industry that followed were only reversed when Spain introduced a feed in tariff to promote solar electricity generation. More recently, similar 'start stop' patterns have also been seen in other countries around the world including Spain, although some governments, such as in Germany, have largely managed to avoid this (see case study four in Appendix 4 for more details.) Given that policies are often also used to drive long term changes in the structure of the industry, governments need to consider the longevity and certainty (as well as a number of other factors, as outlined below) of the policy regimes that they introduce to ensure that continued activity ensues.

Looking across EU-NA, the traditional approach to policy schemes varies by country. Within the EU, the approach has included EU-level and Member State policies and targets which have then been supplemented with bilateral agreements. To drive a move towards renewables, amongst other things, the EU currently has the Renewables Directive that stipulates 20% renewable energy by 2020, and the EU ETS. Within North Africa, the approach to government policy has primarily been at a country level, again supplemented with bilateral agreements. This has allowed countries to favour their comparative natural resource advantages and exercise greater control over the amount of support that is provided to renewable energy. In addition there are a number of global instruments available to support the development of renewable energy in North Africa by developed countries such as CDM and JI.

4.4.2. Key considerations

To arrive at a point in 2050 where the EU-NA power sector is based 100% on renewable electricity, Europe and North Africa have to fully align their energy policies and use them more effectively to direct and, in some cases, drive activity. This report does not seek to identify which type of government policy should be used. Instead it identifies the considerations that need to be taken into account by governments when developing policies in the coming years.

At a general policy level, the key considerations include:

- **Longevity**: One of the key attributes of any form of government policy is its lifespan. For lasting transformation of the industry and commitment by investors there needs to be certainty that new policy will not be withdrawn after a few years. Ideally government policy should have a 20 year lifespan and, if possible, longer.

- **Certainty**: Closely linked to longevity is certainty. Knowing that a particular policy will be in place for a long period of time and exactly what it contains provides the stability needed for the industry and investors. Business decisions can then be made that support the development of programmes of work, the development of supply chains and R&D activities.

- **Transparency**: Well designed policy will enable the market to quickly understand what is being targeted and how. While changes will need to be made to policy over time, e.g. as technology develops and requires less support, if governments are open and transparent with the plans they have for doing this and how the changes will be introduced, the industry and investors will be able to adjust over time.

- **Focus**: To stimulate specific technologies and developments in an industry require policies to be focused. This could be on a particular renewable energy, part of a renewable energy technology at particular stages in its technological evolution, or a combination of closely linked renewable energy technologies. Issuing broad policies will often have the result of encouraging only some of the intended target technologies and activities.

- **Track record**: Investors will also look at a country's track record in setting energy policy and introducing subsidies. To ensure that new policy has the desired effect the following factors also need to be considered: the historical approach to electricity pricing and gas subsidies; the extent to which the new policy covers levelised generation costs (the target being full cost coverage); and whether the purchase conditions for green electricity have been clearly defined such as feed-in tariffs or the obligation of the national operator to purchase green electricity at a preferential tariff, such as via a power purchase agreement.

- **Co-development:** In developing legislation to support the introduction of incentive schemes, it is vital that there is a detailed dialogue between the governments, business and investor community. The effectiveness of policies will be directly related to how much input there has been from the market that ultimately is expected to use them. In addition, given that this roadmap proposes an EU-NA solution, there is a need to engage early on and frequently with North Africa governments as their policies evolve.

- **Costing**: Managing cost is clearly a key challenge of government policy support and intervention. Policies need to be carefully costed and funding needs to be sustainable to avoid 'start stop' scenarios. Equally, mechanisms need to be built-in that allow the policies to be degressive over time, i.e. as the technology matures and less support is needed, the amount of incentive provided is equally reduced. However, this needs to take into account the considerations above.

- **Regional view**: Policy design in the EU to date has mainly been a national matter. Individual countries have developed and rolled out policies that favour particular resource opportunities to help address their national energy demands. This has resulted in an uneven approach and results across Europe and, for investors, the opportunity to policy arbitrage. In future, it is vital that government policy activity is linked to Europe-wide goals, not least as this is the way many investors and businesses approach the market. Having a common EU Energy

Policy and linking individual Renewable Action Plans will allow for more standardisation and the development of complementary policies whilst still allowing for regional differences.

- **Central planning:** The regional view of policy development will also need to include some element of centralised planning. This is important as certain aspects of a renewable power sector should not be left entirely to market forces. The development of a SuperSmart Grid across Europe would benefit from central direction and planning (especially in relation to the setting of centralised standards for metering and sensors), as was done with some of the road and rail infrastructure in certain European countries in previous years. Specific policies should be developed that are regional in nature to ensure that the appropriate infrastructure is developed in the right locations and at the right time.

There are also a number of other direct issues and opportunities associated with a 100% renewable energy power system that will need to be overcome through the strategic development and use of government policy. These include:

- **Managing supply and demand for power:** Compared to an electricity system that relies on dispatchable sources like coal and gas for the largest shares of generation, it is more difficult to alter the fluctuating supply of renewable power to meet fluctuating demand. Some renewable sources of power, such as wind and PV, are intermittent, meaning that grid operators cannot count on them providing any power to the grid at any given time. Overcoming this challenge will require thinking outside the box in four ways. Firstly, it will require more efficient use of those renewable power sources that operators can dispatch, primarily hydro power and CSP with storage. Secondly, it will mean increasing the geographic scale at which the grid is managed. Thirdly, it will require a better understanding and use of distributed generation. And finally, it will require attention to managing demand load, creating incentives for power consumers to shift the time they demand power to those periods when it is most available.

- **Supply chain shortages for different technologies**: To meet the vision for 2050 it will be necessary to stimulate the build-up of the supply chain for a variety of components. Component manufacturing requires high capital investment and, as mentioned earlier, suppliers will only expand their capacity if they are confident that demand will remain high over the payback period of those investments. Making sure that supply chains grow their manufacturing capacity to keep up with the demand of project developers requires policy makers to be clear about a long-term vision for sustained capacity growth. Stability and predictability are key issues to continue to stimulate sustained growth and investment over a long period of time. The ability of supply chains to deliver will also be a key factor for the Infrastructure and Planning enabling area.

- **Infrastructure siting**: Acquiring site approval for new infrastructure, particularly the continuous rights of way required for transmission, requires a legal framework that balances local concerns with the needs of the larger public. In this respect, there are two main, interlinked challenges: permission processes and public concern. The first challenge is to improve the legal framework for acquiring rights of way, ensuring just compensation to landowners and fair consideration of the views of local stakeholders. The second challenge is closely linked to the first: public concern and opposition to new transmission lines. The provision of information to the public about the health and safety issues associated with transmission - and in particular the new technology (for Europe) of HVDC lines - can help the public take an informed view of projects and reduce concern. Issues of public acceptance and infrastructure siting will also be an important issue in the context of CSP development in the North Africa region, despite the fact that from a European perspective the desert areas might be considered 'empty' and 'unused'.

- **Carbon:** The EU ETS has been in operation for a number of years but has had limited impact in driving forward a move to greater use of renewables due to the generally low market price of carbon and continuing uncertainty over international climate policy. A strong and stable carbon price as part of a coherent policy and regulatory framework would help encourage investment in renewables and discourage the fossil fuel generation.

- **Other subsidies**: Governments also need to take greater steps to reduce energy subsidies for fossil fuels. Global assessments[83] put the amount of the subsidy conservatively at more than $300bn annually. Through appropriate policy development, these could be switched to promote decarbonisation and economic growth.

Many of these areas may seem difficult to achieve in tandem. Substantial political will and leadership will be needed over the long term to build the trust with all the stakeholders involved and to ensure that each of the considerations and direct issues and opportunities are appropriately addressed. What is encouraging is that examples exist, as outlined in Appendix 4, where governments and business have previously successfully come together to achieve many of the elements needed to deliver the 2050 roadmap.

4.4.3. The policy roadmap: summary[1]

Within Europe, our roadmap envisages that the first major stream of work in the government policy area will need to focus on information gathering and planning. Driven by the Renewables and Climate Directive and the 2020 targets, there is currently work underway to develop individual Member State renewable energy National Action Plans by June 2010. These plans, plus lessons learned from across the EU, need to be analysed and consolidated to support the development of EU-wide renewable energy targets and trajectories and, also, to support the development of an EU-wide policy landscape to 2050. This will need to carefully consider the requirements of the other system model areas. Sharing of this information with North African countries should also take place to support the steps being taken there.

North Africa in 2010 is starting from a very different place. Provided there is government alignment, the immediate need is for government policy to support the development of institutional capacity and capability in individual countries. By the end of 2010, renewable energy agencies and policies should be in place across a number of North African countries and this will continue in the following years. Discussions on electricity export with the EU (bilaterally and possibly regionally – although this may take longer) should begin in earnest with early agreements being signed to provide certainty for investors and project developers.

The next major stream of activity, no later than 2012, will need to focus on the development of a coherent policy landscape across the EU through the introduction of the necessary policies and regulation. Strategic planning to 2050 will identify areas for further development and the need for additional policy instruments and technical guidelines e.g. to address how Article 9 of the renewable energy directive dealing with electricity imports should be implemented. The focus at this point should also be on looking at how national planning and permitting for infrastructure could be simplified and the development of an EU directive on grid regulation that will support long term EU-wide planning. Through use of the Lisbon Treaty, there is the opportunity to assist North Africa with the approach that is taken to grid and renewables planning by the newly formed government bodies responsible for renewable energy development.

By 2015 the climate and energy targets for 2030 – 2050 should be set to support strategic planning processes. Much of the enabling government policy should be in place which will allow the industry and investment community to begin their planning and development activities. To further support this, additional policy and technical guidelines will have been transposed into Member State legislation, whilst planning and permitting regulations and the EU directive on grid regulation will have been transposed into EU (and where appropriate national) legislation. There will also be greater clarity on how electricity imports from North Africa will be dealt with.

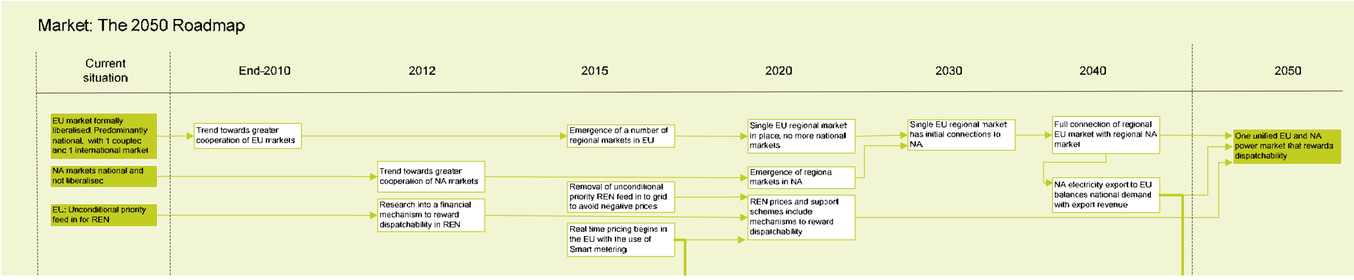
By 2020 all of the necessary government policy to drive pre 2050 activity will be in place. At a strategic level, new renewable energy and climate change directives mandating post 2020 targets will be in place. A review will have happened to determine whether the original 2020 targets were met and, if not, what steps are needed to address this in the coming years. In North Africa, by 2015, most of the institutional capacity and renewable energy policies are in place providing a supportive environment for investment and project development. There is some movement towards a regional approach to renewables given the interconnection of the grid and the building of HVDC cable

[1] See Appendix 2 for further information on the detailed activities required to achieve each policy milestone, and the interdependencies between other enabling area milestones

links with Europe. A free trade agreement is in place between the EU and most/all of the North African countries which then allows for an increase in the alignment of energy policies such that, by 2050, there is full alignment.

At 2030, 2040 and 2050 similar reviews by the EU to determine whether the original targets were met will take place. Government policy activity at this point will be focused on reviewing and managing the existing policy landscape, introducing policies that support the decommissioning of existing fossil fuel generation plants, looking at how better integration can be achieved with North Africa and planning the post-2050 policy landscape and targets. For North Africa, the opportunity exists for long term planning post-2050 and the consideration of sub-Saharan energy projects.

4.5. Roadmap enabling area 2: Market structure



4.5.1. Introduction

The current European and North African power systems are largely based on fossil fuels and nuclear power. They have developed over a long period of time driven by the need to achieve a political and economic optimisation of electricity mix, and have, until very recently, not had to account for external costs and climate impacts.

The market structure in place today reflects this. The European electricity market is still, despite its formal unification, a fragmented market consisting of a large number of national power markets with different levels of interconnections to neighbouring countries. The European markets are all formally completely liberalised[56] but, due to the market fragmentation and the weak interconnections, the national champions still dominate their former monopoly markets. As a result, competition in the European power markets is still weak.

The European power market is, however, now beginning to transform. Following the issue of the first liberalisation and internal market directives, there has been some progress. There have also been ongoing debates about how to improve the design and functioning of the market, the need to further unbundle the national champions and about market unification. What this shows is that, in most respects, electricity remains a national rather than a European affair[23].

The North African markets are still very much national markets. They are not yet liberalised, although there is some work underway in most countries in the form of unbundling and third-party access to the grid. The countries are all still completely dominated by a national, state-controlled utility with the state also controlling the pricing through strong subsidies on electricity consumption[71]. This has led to very low electricity prices and electricity production of any kind in North Africa is generally far from economically viable.

From a structural point of view, although all five national grids and markets in North Africa are interconnected, only the Moroccan, Algerian and Tunisian grids are synchronous. These three grids are also synchronous with the continental European grid, and the Libyan and Egyptian grids are synchronous with Jordan, Lebanon and Syria but the electricity trade has been very limited.

4.5.2. Key considerations

- **Market design:** The power market as it has existed since market liberalisation in the 1990s is built precisely around the task of matching supply to demand in a way that takes advantage of the cost structures of today's main technologies. Power suppliers submit bids on the spot market at prices reflecting their marginal costs. The system operator then accepts bids in the 'merit order' of prices. The price that all suppliers receive is fixed by the most expensive bid accepted, which changes according to demand. The high wholesale price during peak load periods and the even higher price during scarcity periods make it possible for operators to cover their fixed costs. This market design may not meet the needs of system covered by 100% renewables, which are to allocate dispatchable power (hydro and CSP) efficiently, and to ensure appropriate profitability for power suppliers even when all have high fixed costs and low marginal costs. More research is needed to identify an alternative market design for both Europe and North Africa and to consider if, when and how a shift to a new market design will become necessary.

- **Regional TSO engagement:** in addition to efforts by TSOs to work together more closely within the EU and North Africa, there will also be a need for these TSO groupings to engage more closely with each other to share plans and lessons learned. A mechanism will need to be set up to support this EU-NA interaction. A further role these groupings could play is in reaching out to the public to address concern and resistance to new projects. A good example of this is the Renewable Grid Initiative[84].

- **Security of supply**: Constant access to affordable energy is a prerequisite for modern society. With trade in primary energy and energy carriers such as electricity, has come the fear that supply interruptions can be used as a political weapon. A future energy vision for Europe that relies on a large share of electricity generated outside of Europe, such as in North Africa, will make some people anxious. There is reason to be optimistic, however, that the security of supply will be even greater under the vision for 2050 than it is today for both Europe and North Africa, primarily due to increased diversification in power source and generation location.

- **Public engagement:** Closely linked to the previous point are issues of public acceptance and concern about a move to a greater dependency on renewables and, in the case of new transmission lines, health and safety issues. Appropriate and adequate awareness campaigns, advice, support and means for the public to engage with policy makers and energy regulators will need to be put in place in the short term in both Europe and North Africa to allow infrastructure work to commence in the coming years.

- **Institutional capacity**: For North Africa there will be a short term challenge to establish the institutional capacity and capability to plan and manage the transition to a power market that is more heavily reliant on renewables. Help and assistance from Europe should be extended to individual North African countries to ensure alignment between markets is in place to support the construction plans.

- **Governance**: There are currently regulators that monitor and manage the grid operators. Further work will be needed to understand how this needs to evolve when there is greater interconnection of grids and the introduction of SuperSmart Grids. On the generation side, with a greater diversity of renewable energy generation sources and locations, there also needs to be some way of coherently governing this. A better understanding and use of distributed generation by grid operators in both Europe and the North African countries will be essential to ensure that demand can be met.

- **Electricity pricing**: A power system that relies more heavily on renewable energy will need to review how electricity prices are set (see also 'market design' above). In particular, how to value dispatchability that is provided by sources such as hydro and CSP with storage. Across North Africa the challenge is the current amount of subsidies that lead to low electricity prices. There needs to be a gradual reduction in the amount of the subsidies to adjust the electricity prices to international levels. This will then also make investment propositions more feasible for external investors.

- **Electricity labelling**: To achieve public acceptance within the EU for the financing of renewable generation and transmission infrastructure, there will be a need for a consistent verification system to confirm that transported subsidised electricity has actually come from renewable plants. The EU electricity labelling work is a step in the right direction but further work should be undertaken to embed this across the region.

- **Legal and regulatory framework:** All investors in renewable projects will, as outlined above, be interested in what the local public policy is for the support and the promotion of renewable energies. This would take into account what the realistic and quantitative renewable energy objectives set out by the government in the long term will be in a particular country. Also impacting the decision will be an understanding of how transparent and predictable the procedures for clearances and permissions is, the availability of long term commitments and the contract security, whether there is guaranteed and free access to the network (including any grid connection standards), clear roles and contracts for the EPC contractor, O&M contractor etc., the likelihood and amount of any possible network losses, and the challenges associated with grid connection and other supply and demand side issues.

- **Green industry**: The ability for countries to develop green industries is often cited by governments as a driver for supporting the development of renewable power. This will not happen as a matter of cause. Governments in both Europe and North Africa will need to give careful thought how these will be encouraged and supported in the years to come, ideally on a regional basis. Effort will also need to be focused on how traditional businesses can best enter the green market as part of a new expansion of their existing business models.

4.5.3. The market structure roadmap: summary[2]

In Europe, from a 2010 starting point of a collection of loosely unified but fragmented national markets, our roadmap envisages that discussions will have started to make good progress by 2012 on addressing a long term power market design. Lessons learned will have been collected and further research carried out to understand how the functioning of the liberalised market can be improved. The unbundling of national champions has continued in all Member States. National markets have started to coalesce into regional markets, the main ones being the North Sea, the Baltic and the Mediterranean. In North Africa the focus has been on the set-up of institutional capacity to oversee a power market more heavily reliant on renewables. In both regions, agencies have also been established to oversee public consultation and engagement on the transformation plans.

In the run up to 2015, supported by International Renewable Energy Agency (IRENA) and equivalent agencies, the European and North African governments have started to review and improve their planning and permitting requirements, and legal and other investment requirements have been updated to provide the required certainty for investors. High level plans for grid infrastructure, upgrades and links have been developed for both Europe and North African countries. Early exports of electricity on a bilateral basis take place between Tunisia and Italy. The carbon market has also developed further and measures have been introduced to create a more realistic price for carbon in the coming years.

By 2020, all national EU markets have been united with at least one neighbouring country and no solely national markets remain. The price of electricity reflects the larger role of renewables and mechanisms exist to reward dispatchability. In North Africa all national grids are now well connected forming the basis for a regional grid. In both the EU and North Africa there is ongoing development of a green job market and industry.

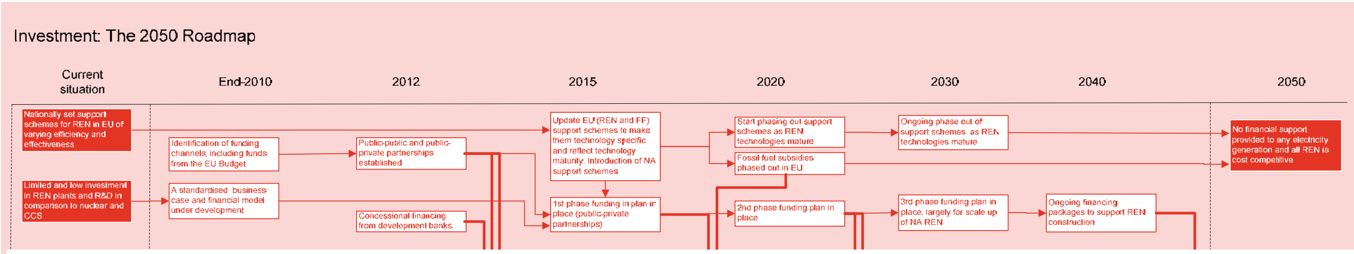
By 2030 regional markets in Europe have interconnected and the achievement of 2030 targets leads to recommendations for further changes to the market to support 2040 targets. An increasing number of HVDC links have been built to connect to North Africa and Europe. The unbundling of power companies is nearly complete.

By 2040, the final steps to connect the EU and North African markets are underway and there is near full connection. There is electricity trade in almost all directions between the North African countries, whilst the electricity flow across the southern European border is primarily directed into Europe. There are a number of large European power companies that have significant, but not market-controlling, shares of generation and wholesale within Europe and North Africa, and a number of North African companies that are beginning to dominate the export trade to Europe. The electricity production in North Africa balances domestic demand with export revenues.

By 2050, the European internal power market has been completely unified for a long time, and has been united with the North African country markets. The power companies have been vertically and, where necessary, horizontally unbundled, the grids are under strict control and are operated and optimised in a European-North African perspective. The increased number of equal players on the market, together with transparent market regulations, has ensured the proper functioning of the entire European-North African power market.

[2] See Appendix 2 for further information on the detailed activities required to achieve each market structure milestone, and the interdependencies between other enabling area milestones

4.6. Roadmap enabling area 3: Investment and finance



4.6.1. Introduction

The investment community has, to date, largely approached the renewables industry as just another investment opportunity, albeit with higher risk and uncertainty. Given the small size of the market, existing economic models for other opportunities have been used to determine key factors such as acceptable rates of return and mainstream instruments have been used to support the financing of renewable projects. Investment that has taken place has been driven by specialist investors, in-country governments and, for North Africa, by MDBs as part of their wider development agendas. Although the trend is one of steadily increasing investment over the past decade, on the whole, the sums committed for most renewable energy technologies have not been sufficient to result in significant increases in installed capacity compared to conventional sources.

Low amounts of investment have only been part of the reason for the slow uptake of renewables. Many countries have also been unwilling to commit to major changes in their existing power systems out of fear among many industry and policy stakeholders that the macroeconomic costs of doing so would be high and could bring significant job losses (for example in coal regions). It would be a mistake if this view was accepted by the investment and business community. Despite the fact that there will clearly be winners and losers, the anticipated macroeconomic costs of the 2050 transition are likely to be low and the benefits high. Recent studies have shown that the costs for making CSP competitive with coal – excluding the price of carbon and all environmental external costs of coal power – may be as low as €20-45bn[35, 85]. Split between all European countries and over more than a decade, this is not a large sum: E.ON alone plans to invest €30bn mainly in transmission and fossil-fired generation capacities in the three years 2009-2011[86].

The availability of finance and investment to support the 2050 vision will be primarily driven by costs and returns on investment. Costs of materials, construction, and operation are most commonly analysed as LCOE and will be different for each of the renewable energy technologies at each stage of their development. Costs will, in turn, drive returns on investment for investors and determine the likelihood that further investment will be forthcoming.

The costs of generation for all renewable energy technologies will fall in the future for two reasons[87-88]. Firstly, as a result of specific investments in R&D and through simple learning by doing (assuming that lessons learned are shared). Secondly, as the scale of manufacturing of equipment and components increases, mass production replaces piece work and costs in the supply chain fall. As a rule of thumb, costs fall by 10 – 15% every time the total installed capacity of a renewable technology doubles. By comparison, conventional, centralised technologies have typically had learning rates of typically 5%, whereas nuclear has had negative learning rates and tends to get more expensive with time[78].

This report is not an attempt to calculate the anticipated costs of delivering the 2050 vision but we explore the issue of individual renewable electricity costs by technology and the costs associated with tackling climate change more broadly in Chapter 5.

4.6.2. Key considerations

- **Information sharing:** The investment community will price renewable energy investments on the quality of information that they have available on particular types of technology as well as individual project opportunities. If the investment community has better information about the technology, the projects and the policy landscape then risk premiums associated with financing renewable projects will probably fall. In addition, better collation, sharing and use of industry-wide information on technology components, track records etc. will also be important in attracting more investors into the sector.

- **Engagement**: There exists the opportunity to engage the wider investment community in the development of generation and transmission infrastructure plans at an early stage. By doing so, financial and investment constraints could be identified at the start and help to shape the optimal approach for timely delivery of the projects. Currently, investors are often approached at the end of a project development when many of the details are already in place and there is less opportunity for change.

- **Tools and templates**: Another opportunity is greater customisation and standardisation of tools and templates used by the investment industry to support financing decisions. Appropriate business case and financial model templates could be developed for individual renewable energy technologies. These could be shared with project developers and technology companies to provide greater clarity on the acceptance criteria and supporting information needed to gain approval. Governments and utilities could also develop standard long term power purchase templates that would form the basis for the offtake.

- **Financial products**: In addition to tools, there is also a need to develop further financial products to support the scale up of the renewable energy industry. Especially in the case of less mature technologies where track records are still short, the provision of, for example, insurance products that will guarantee the performance of components for 25 years will help to remove much of the perceived risk. Further products should be developed as short to medium term support as renewable energy technology becomes more established.

- **Project specifics**: In addition to the point raised above for the industry as a whole, there is also the opportunity to standardise and develop common standards for the development of project information. Financial models looking in detail at information on the financial viability / economics of the project, including whether 100% of the financing was assured (sovereign loan, guarantee agreements, support by manufacturers, equity participation etc.) and the cost coverage, could be developed. Information on a number of other metrics could be standardised to a greater extent, such as the likely cost of installed kW and grid connection costs, the capacity factor and plant availability, the purchase conditions of generated kWh (amount and duration of guaranteed tariff), the debt to equity ratio for the investment and expected return on equity rate, the CO_2 mitigation costs, the storage capacity and whether proven technology has been employed (including an analysis of the pros and cons of the technology). This would enable key metrics to be prepared more easily by project developers and understood more quickly by investors.

- **Loading of investments:** For many renewables, it is worth noting that most of the investment costs are typically front loaded when compared with other fossil fuel options. There is no fuel supply 'tail' of costs that continues for the life of the generation plant. Financial models could do more to provide credit for this annuity of low operating costs that results once the initial investment has been paid off.

- **Risk mitigation mechanisms**: Governments and the investment community should work more closely together to identify other financial risk mitigation mechanisms that could make the financing of renewable energy projects more attractive to private investors. Public sector loan guarantees and credit enhancements are two examples of these. Further ones should be developed and promoted. In addition, exploring the opportunities for novel public:private and public:public contracting arrangements for large scale renewable energy and transmission opportunities should also help to reduce risks.

- **Coordinating investment**: Currently, most renewable energy investments are made on the basis of specific projects with a tier of organisations involved, each contributing a part of the funding to share the risk. As projects get larger and more frequent, this may need to change. Some projects may need to be driven almost entirely by government investment, e.g. grid connection for new renewable energy generation plants. The costs of upgrading grids may need to be socialised. The existing pool of investors may need to be expanded to include other bodies and organisations that are not currently involved, e.g. Renewable Energy and Energy Efficiency Partnership (REEEP) and Global Environment Facility (GEF). Communities may also want to be involved in local projects. Better coordination of this investment activity will be required to ensure that available funding is best used.

- **Capacity building in North Africa**: The vision that this report proposes involves substantial investment in North Africa to develop renewable energy generation and transmission capacity. Whilst much of the investment will still be raised via established financial centres in Western Europe and elsewhere, the institutional capability and capacity in North Africa will also need to be further developed. This is important not only to provide a more favourable investment climate but also to enable these countries to engage more actively with the investments being made.

- **Energy efficiency**: A vision of ongoing investment to 2050 will not be sustainable for governments or financial markets unless there is some ongoing return. Consumers will be reluctant to pay ever higher bills for electricity. The focus for investment should also be on achieving energy efficiency savings that can then be pooled and reinvested in new renewable energy opportunities going forward.

- **Other support:** Other financial support that is currently being provided to fossil fuels should be reduced and redirected to support investment in renewable energy opportunities and the move to a decarbonised power sector. In addition, policies need to be introduced that internalise all external costs for all energy technologies. This will take time but, in addition to potentially releasing large amounts of funding, it will also send a clear message to investors that renewable energy will now be the focus for the power sector going forward.

4.6.3. The investment roadmap: summary[3]

Looking across the EU today, investment in renewable energy is largely driven by nationally set support schemes of varying efficiency and effectiveness. There is a limited and low amount of investment in renewable energy and renewable energy R&D in comparison to, for example, nuclear and CCS. In terms of renewable energy infrastructure project opportunities, the investment industry has already largely organised itself at a regional level.

What will need to happen in the period 2010 – 2012, driven by developments in the government policy area, is the mobilisation of large amounts of new investment. Additional public and private funding channels will need to be explored and encouraged (including additional concessional funding) and appropriate contracting models developed. In parallel, steps will need to begin to customise and standardise business cases, financial models etc for renewable energy opportunities.

From 2015 onwards, our roadmap envisages that government policy will have introduced updated support schemes across the EU for renewable energy and fossil fuels. Supported by the new EU budget, these will be more technology-specific and aligned to the maturity of the technology. This will coincide with the completion of the first phase of investment mobilisation which will have taken place in a more coordinated manner and will be scheduled to repeat on a five to ten year cycle to support subsequent phases of investment. Standardised tools, templates and insurance products will be in common use to support the development of new renewable energy projects.

By 2020, support schemes for certain technologies will start to be phased out, e.g. wind and fossil fuels, with all support schemes then gradually phased out in the run up to 2050. Renewable energy investments are regarded as more mainstream and energy efficiency savings are starting to come through for reinvestment. There is greater participation by a wider range of organisations in the financing of renewable energy projects including community participation. Policies are being developed that begin to internalise the external costs for all energy technologies to create more of a market pull for renewable energy technologies.

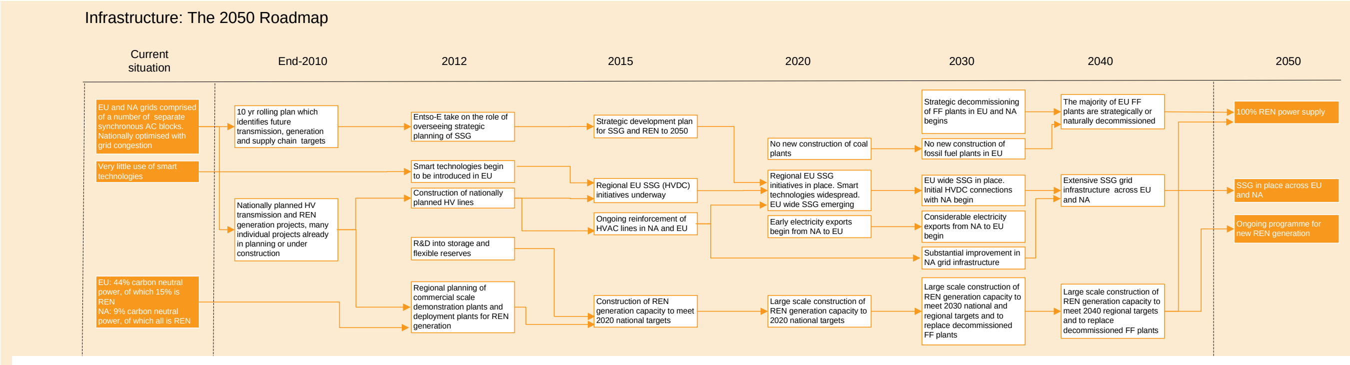
[3] See Appendix 2 for further information on the detailed activities required to achieve each investment milestone, and the interdependencies between other enabling area milestones

By 2030 more of the renewable energy technologies are becoming cost competitive e.g. CSP, and subsidies can be released and directed into support for other less mature renewable energy technologies and, where appropriate, to R&D budgets. Renewable energy projects are viewed as mainstream investment opportunities helped by risk mitigation mechanisms. Energy efficiency savings are now providing a more substantial portion of the new funding for renewable energy project investment. This continues into 2040 and 2050 such that by 2050 renewable energy generation is fully cost competitive, no financial support is needed any longer and renewable energy projects are seen as a mainstream investment opportunity.

North Africa is starting from a very different place to Europe in 2010. To date there has been very little foreign direct investment in renewable energy outside of MDB programmes of work. There is a need for renewable energy incentive policies to be developed in the coming years, alongside institutional capacity building, to create a more attractive environment for investors. This is helped by the formation of specific public:private partnerships. By 2012, the investment environment across North Africa has become more transparent and government policies are in place allowing the first set of renewable energy incentives to be introduced. The first phase of funding that has been mobilised is used to support a wave of renewable energy generation construction. Information is collected on existing programmes of work and lessons learned are used to support the planning of the next wave of renewable energy plants.

By 2020 electricity exports to Europe are underway. Funding has been secured for the next wave of renewable energy generation construction, supported by additional World Bank and European Investment Bank funding. This cycle continues into 2030 and 2040 resulting in a substantial build up of generation and transmission capacity. As EU and domestic demand is satisfied, attention turns to the funding of possible sub-Saharan renewable energy project opportunities.

4.7. Roadmap enabling area 4: Infrastructure



4.7.1. Introduction

The generation and transmission infrastructure in place today across Europe and North Africa reflects the way in which fossil fuels (and to a lesser extent nuclear technologies) have dominated the power sector over the past century. Grid systems have been developed using AC technology with generation infrastructure located close to consumption centres. Generation infrastructure has, until relatively recently, also been heavily fossil fuel based with coal dominating in some EU countries and gas and oil playing a larger role in North Africa. More recently, countries have been faced with this infrastructure reaching the end of its useful life and, with increasing demand; there is now a need to decide where the replacement and additional capacity will come from.

As outlined previously, when combined with climate change concerns, this provides an opportunity to embrace renewables more broadly than has been done to date. Doing so will represent a massive change to a ‘business as usual’ approach. At an enabling level there will firstly need to be substantial changes to the transmission infrastructure across Europe and North Africa. Examples of these include the need to manage the grid on a greater geographical scale than before and the need to ensure that there is a better understanding and use of distributed generation. The need for a greater focus on dispatchability and demand management has already been touched on in the government policy section earlier in the roadmap. It will also have implications for the infrastructure that needs to be constructed and the need to scale-up the use of ‘smart’ technologies.

At a generation level, one of the consequences will be the decommissioning of existing plant, but also the opportunity to replace this with renewable energy alternatives. This change in direction will need to be supported by further EU directives that disincentivise, for example, the building of new coal plants. Initially unpopular, once dispatchability has been rewarded and the appropriate renewable options with storage are in place, the concerns that currently exist around whether renewables will ever be able to successfully meet baseload requirements will abate.

4.7.2. Key considerations

- **Grid expansion:** One of the pre-requisites for the 2050 vision is a major expansion and improvements to the existing HV grid. Long distance transmission will be vital to allow regional variations in generation and demand to be balanced out and to allow for the smoothing of intermittency from renewable sources of power. In addition, TSOs will need to consider interactions between existing country level grids in a more coherent manner than happens today. A body like ENTSO-E will need to oversee and drive this.

- **Regional and long term planning**: Linked to the long distance transmission point above, future infrastructure capacity and development planning will need to take place at more of a regional, rather than national level. The production of the components and the construction of the grid will in themselves also be major programmes of work and need to be carefully planned. Finally timing will also be critical as the grid is by many seen as the precursor for the large scale development of renewable generation sources. Rollout plans to develop the siting of new generation infrastructure will also need to be centrally planned.

Note: Breaking news as this report goes to print is the release by ENTSO-E on 1 March 2010 of their pilot Ten-Year Network Development Plan (TYNDP). This is a forward-looking proposal for electricity transmission infrastructure investments across 34 European countries. This first release of the TYNDP for public consultation puts forward a total of close to 500 investment projects, worth €23-28billion over the first five years[15].

- **New measures:** A larger grid and greater amount of renewable generation capacity will also bring the need to consider new ways of assessing costs, benefits and environmental impacts across the EU and North Africa. There will also be a need to improve EU-wide monitoring of power flows (and weather forecasts) to anticipate and manage congestion, demand and weather related issues.

- **Decommissioning:** One of the central tenants of the 2050 vision is the large scale decommissioning of existing fossil fuel and nuclear plants on a scale not previously achieved. Driven by the appropriate government policy there will be a need to develop further expertise and capacity to deliver this.

4.7.3. The infrastructure roadmap: summary[4]

As of 2010, the European transmission gird is composed of five asynchronous AC blocks with limited interconnectivity and is subject to grid congestion. The EU power supply is reliable. Only 15% comes from renewable sources. In the case of North Africa, the grids are physically but not practically inter-connected and only 9% of the power supply comes from renewables.

By the end of 2010, our roadmap envisages that ENTSO-E has taken on the role of consolidating existing information on grid infrastructure across the EU and is in discussion with its North African equivalents. This information will help develop an understanding of the existing project work underway and support the development of a rolling 10 year transmission infrastructure plan that identifies future transmission, generation and supply chain targets. A start will also have been made on collating best practice approaches to permitting and approval procedures across the EU. By engaging with North African countries on all of this, they are able to use this information to support the establishment of in-country institutional capacity which, in turn, will help them better plan their future infrastructure development programmes of work.

By 2012, our roadmap assumes that ENTSO-E has taken on the development of EU-wide transmission plans and new programmes of HV line construction have started. The EU SET plans have completed their consultation period and are the key tool in coordinating the development of renewable generation capacity. Both ENTSO-E and the European Commission are now working closely with their North African counterparts to ensure that there is a coordinated approach to the slowly increasing programme of work including the building in North Africa of commercial scale demonstration plants and the construction of factories to support supply chains. With the introduction of additional EU directives and guidance, there are more applications being submitted for renewable energy generation facilities across Europe and an increasing focus on dispatchability and smart technology.

By 2015, the infrastructure development in Europe and North Africa continues. The ENTSO-E and SET Plan work programmes are closely linked and have been mapped out to 2050. A coordinated plan and strategy for the decommissioning of fossil fuel plants has been agreed by EU Member States to meet the 2050 targets. There are a number of regional EU Super Grid initiatives underway (North Sea, Baltic Sea and the Mediterranean Sea) to complement the increasing number of renewable generation plants being built. The first new HVDC cable link between Europe and North Africa goes live and early electricity exports to Europe begin. Best practice permitting and approval procedures have now been collated and are shared routinely to support the new work programmes.

By 2020, construction programmes have delivered the goals of the proposed Renewable Action Energy Plans and offshore wind and other renewable technologies now provide a significant part of EU-NA total electricity needs. There is no new construction of coal plants and decommissioning of other existing fossil fuel plants begin. In North Africa, the large scale construction of renewable generation sources, especially solar begins, the demonstration

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[4] See Appendix 2 for further information on the detailed activities required to achieve each infrastructure milestone, and the interdependencies between other enabling area milestones

plants having proved the viability of the technologies and the export of the electricity to Europe. Across Europe the regional Super Grids are now in place supported by increasing use of ‘smart’ technologies and a better understanding of how the European grid can cope with increased amounts of variable renewable power. Linkages are beginning to be made between these that will enable them to transform into regional and then, later, an EU-wide SuperSmart Grid.

By 2030, substantial progress has continued with the goals of the 10 year plan met and used to develop the outlook for the coming 10 years. Offshore wind, CSP with storage and other renewables now provide the largest share of total electricity generation across the EU. There is now a 10+ year understanding (supported by extensive programmes of R&D) of how the EU grid system is able to cope with increased amounts of variable renewable power connected to the grid. Further work is undertaken to increase the amount of balancing power plants and storage technology. In North Africa more than 10 new HVDC cables are now in place to support increasing electricity exports to Europe. Thoughts now turn to increasing development activities across North Africa e.g. desalination, electromobility and, in the longer term, export schemes to sub-Saharan countries.

By 2040, transmission and generation construction projects have been running for 30 years. The new renewable energy generation facilities now provide the vast majority of the total electricity generated across Europe and North Africa. Plans are updated for the coming 10 years and a review is carried out of the lessons learned and changes that may need to be made as 2050 approaches. The decommissioning of fossil fuel plants is now also nearing completion in Europe and underway in North Africa.

By 2050, the SuperSmart Grid infrastructure is in place across Europe and North Africa. The connection of the regional EU mini SuperSmart Grids has resulted in an EU-wide SuperSmart Grid and this is connected at a variety of points to the upgraded and extended North African grid. The EU power supply is now based on 100% renewables with North Africa close behind. Experience of this construction programme has informed plans for the 2050 – 2100 period and, supported by best practice, lessons learned and planning knowledge, work begins to build the next generation of renewable generation plants. In North Africa, attention turns to further domestic development plans and to begin the construction of sub-Saharan renewable energy links that will support development plans in those countries.

Some key existing building blocks

Many existing governmental, private sector, and civil society initiatives provide important building blocks for the decarbonisation of the power sector and the development of a more effective grid system. They are important starting points for the roadmap. In turn, a common approach, such as that illustrated by the 2050 roadmap, would give them added impetus and direction.

EU Energy Policy: The European Commission announced its approach to delivering a new European Energy Policy in 2007. This is being taken forward in part by the Strategic Energy Technology Plans[89] (SET Plans) and Technology Roadmaps. These are currently under development and aim to both encourage the development of a variety of low carbon technologies and ensure that policy objectives, specifically the 2020 targets, have a greater chance of being met.

Desertec Industrial Initiative (DII): Twelve founding companies across Europe and North Africa came together in July 2009 to announce that they would work together to analyse and develop the technical, economic, political, social and environmental framework for CSP electricity generation in the North African deserts and transmission of a significant proportion of this electricity to the EU[90]. This initiative is currently still forming its plans and is in the early stages of engagement with governments.

Mediterranean Solar Plan (MSP): Launched in July 2008 as part of a wider Union for the Mediterranean initiative, the objectives of the MSP[91] are to deliver 20 GW of new renewable electricity capacity by 2020 across Mediterranean countries, to improve the transmission grid infrastructure with a view to enabling imports of electricity to Europe, and to create the appropriate framework conditions to support stable investment and development conditions. Good progress has been made in some areas, and with Spain taking over the Presidency in May 2010, there is the opportunity for substantial progress in the coming years.

North Sea Super Grid Initiative: In December 2009, nine European countries (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom) announced that they would work together to develop a common vision for a North Sea and North West offshore grid.

World Bank: In December 2009, the World Bank's Clean Technology Fund (CTF) Trust Fund Committee endorsed a Middle East and North Africa regional CSP investment plan[29] to provide up to $750 million in CTF resources. The objective of the plan is to support the deployment of 1GW of CSP capacity over a 6-8 year time frame and the development of transmission infrastructure to facilitate increased solar electricity trade. The programme is looking to commence in 2010.

Major Economies Forum on Energy and Climate (MEF): To promote continued economic growth and sustainable development as part of a vigorous response to the danger posed by climate change, the Leaders of the 17 partners of the MEF established the Global Partnership on 9 July 2009 to develop plans that would drive and deploy transformational clean energy technologies[92]. A number of reports were issued in December 2009 to support this aim and the COP15 discussions in Copenhagen.

5.

Opportunities and consequences

"The import of solar power at a fair price from North Africa into Europe is a necessary step to reach sustainable energy supply in the region. In Algeria and Morocco, local financial support mechanisms, similar to the feed-in tariff in Germany, will not suffice to stimulate the build up of a local supply chain. Without some local production, the opportunity for positive economic and social effects is much reduced and the positive impacts on the environment are small. The recently published Moroccan solar plan represents a signal towards Europe. A strong European partnership can support Moroccan efforts in local sustainable development and open a new promising economic and social partnership for Europe."

Prof. Abdelaziz Bennouna

Centre National pour la Recherche Scientifique et Technique, Morocco

5. Opportunities and consequences

In the previous chapter, the heart of this report, we outlined a roadmap for achieving a European power sector based on 100% renewable generation. Decarbonisation and the maintenance of power system reliability are central to the vision and the roadmap. It will be a complicated puzzle to put together and, while possible, there is significant potential for missteps to occur, leading to a deceleration or even a complete stop in the rate of change. Nevertheless it is a vision that we consider to be achievable if political leaders choose to embark on this course.

In this chapter, we look at the consequences, opportunities and the costs associated with achieving the 2050 vision that we have outlined. We focus on the five that we see as most crucial: security of electricity supply; costs of transmission lines and renewable infrastructure; non-climate environmental consequences; sustainable development in North Africa; and addressing the climate change challenge globally, not just regionally.

5.1. Security of supply

Following over a decade of increased liberalisation of the energy system, the EU reacted to the disputes taking place between Russia and the Ukraine in 2007, which endangered gas supplies to Europe. Under the German presidency in March 2007, the European Council adopted its first Energy Action Plan, which placed security of supply, along with competitiveness and environmental sustainability, as a guiding principle for European energy policy[1]. By promoting a common approach by European countries towards the rest of the world in order to maintain the continent's access to imported energy supplies, the Energy Action Plan reflected worries about energy security that were perhaps greater than they had been since the oil supply interruptions from the Middle East in the 1970s.

There are good reasons for policy-makers to be concerned about supply interruptions. Currently, about 50% of Europe's energy demand is met with imported fuels, as discussed in Chapter 3.3, and there are projections that this could increase to 70% in the coming decades[1]. Interruptions of supply can cause significant economic harm. While past supply interruptions have been for oil and gas, electricity would be a concern if Europe were importing large amounts of power or fuel for generation. Blackouts impose the most visible costs on society but, even in the absence of a blackout, the value of lost load is two orders of magnitude larger than the electricity price: a good estimate of this is 8 €/kWh[93,94]. Due to the very high costs of a blackout, every power system has control capacities which can be brought online within minutes following a disruption.

In the current continental European grid, some 20 GW of additional capacity can be started up within 15 minutes and operated for at least a number of hours, much of it can operate indefinitely, and much more spare capacity can be fired up within a couple of hours[14, 95]. If there was a cessation of imports of 25 GW, Europe would suffer large scale blackouts and large economic damage. However, due to the control capacities and capacity buffers, system stability would be restored within a few hours. Assuming a worst case, 10 hours of an 'on average' 25 GW blackout would cost Europe €2bn. However, that would be it - the costs for the rest of the disruption, regardless of how long it lasts, would be zero. If, for example, the interruption lasted three weeks, the costs for Europe would still be €2bn, equal to 0.3% of its total GDP for this period.

There are two reasons to believe that the roadmap described in this report would not carry new energy risks and may, indeed, represent a lower level of risk than a continuation of the status quo. The first reason stems from the fact that the 2050 roadmap, even with its heavy reliance on power from North Africa, would actually lead to a net decrease in the reliance of the power sector on imported energy, as well as to a greater diversification of the countries from which those imports stem. The initial set of milestones towards 2050 will displace many of the existing fuel imports with renewable power generated on European soil, from its coastal waters and its neighbours to the south and east.

After 2020, CSP from southern Europe and more generally the North Africa region will play a larger role. Both developments will substitute largely for imported coal, gas and uranium. After 2020, the changes will also begin to reduce the need for gas, while a gradual shift towards electric vehicles may also lead to a decline in the need for imported oil. Current fossil fuel imports - especially natural gas - come from very few countries, defined by the location of the resources underground. By contrast, the solar energy resource in North Africa is spread over a much larger number of potential trading partners, most of them with the possibility of feeding power directly to Europe via an undersea cable. Reliance on any one country, similar to the current reliance on Russia, will decrease[57].

The second reason for optimism stems from the nature of electricity production and export, which in theory are less useful as a political weapon than gas or oil export. In the case of oil, any quantities that the exporting country embargos today can be shipped tomorrow so the total costs for the exporter over time is minimal. Possibly, the exporter can even profit from a supply disruption, due to increased prices following the crisis. Also, it has not been possible for importing countries' transportation systems to quickly shift from imported petroleum to a different fuel source, such as oil derived from coal, and so the importers' costs of oil supply embargoes have been great.

In the case of electricity trade between Europe and North Africa, the situation would be reversed and the exporter would not have a position of power over the importer. Consider again a three-week interruption of 25 GW of power, which would cost the EU 0.3% of its GDP during that period. Assuming lost profits of 0.05 €/kWh, this would result in lost revenues to the supply country of €630 million, equivalent to 50% of the current GDP over this three week period of a small country such as Tunisia or 10% for a large country such as Egypt. These are export revenues that would be forever lost since the electricity cannot be stored or, in the absence of other interconnector grids, diverted to other markets. Cutting the electricity supply for Europe is a battle the exporter cannot win and, therefore, would be very reluctant to try.

What is crucial for European policy-makers is to ensure that supply interruptions do not lead to blackouts as the costs of blackouts are much higher. For this, current policies governing system redundancy would need to be extended. The current margin between dispatchable capacity and system peak load is more than 100 GW, or 20% of the system peak load, most of which can be brought online within hours and operate indefinitely[14]. As mentioned previously, more than 20 GW can be brought online within 15 minutes[14, 95]. Importing more than this from a single country would be an unlikely outcome of the 2050 roadmap but, if it were to occur, then it may be necessary to improve on these protections.

What about terrorist attacks?

A concern for many Europeans when contemplating the North Africa region is terrorist attacks. These are perpetrated by non-state actors, usually with the goal to cause immediate and visible disruptions to society, such as a large scale power blackout coupled to losses of life. But this would be difficult for terrorists to accomplish. At current system operation margin levels, at least 3 GW must be disrupted suddenly and without warning for a blackout to happen[26]. This is currently the size of the largest allowed unit, including HVDC feeder lines, in the Union for the Coordination of Transmission of Electricity (UCTE) grid area. Due to the decentralised nature of renewable power stations (a wind power tower has up to 6 MW, each block of a CSP plant up to 50 MW), disabling more than 3 GW in generation capacity would require a coordinated set of attacks over a very large geographic area, more akin to an attack by a national army rather than a terrorist organisation.

More destructive would be to focus on system bottlenecks, namely the HVDC feeder lines through the desert. This certainly is a possibility. If all parallel lines operate at full load, destroying lines with a capacity of more than 3 GW would be enough to cause a blackout in Europe. In the best case – for the terrorist – this would be two lines of 3 GW each. In the worst case, this could be seven or more lines of 500 MW each. If the lines do not operate at full load and there are re-routing possibilities, much more capacity must be destroyed simultaneously. This is still possible, but difficult. Such a blackout would not be large scale and the supply shortage would similarly not be very large compared to available capacity. As the preceding discussion highlighted, the power system will be operating with significant reserves and such a small-scale blackout would be corrected quickly.

Furthermore, unlike a similar attack on an oil tanker or gas pipeline, an attack on a transmission line would create little loss of life or collateral damage beyond the force of any explosives used in the attack itself – pipelines carry explosive goods, power lines do not – and so the main effect of such an attack would be the blackout and related economic losses for the exporter and importer countries. Terrorism has to be taken seriously and measures taken to protect transmission lines but terrorist attacks are not a large threat to European security of supply.

5.2. Costs

Scientists have recognised the threat that climate change presents to humanity and the environment for decades. In 1992, countries signed the UNFCCC, pledging to reduce their greenhouse gas emissions to prevent "dangerous interference" with the climate system. Over time it became clear that the scale of such reductions would have to be close to 100% and countries pledged to make this happen. Yet very little has happened. The main argument to explain this is that eliminating CO_2 emissions would be too expensive. Indeed, the recent global recession, while resulting in a decline in emissions as a result of a slowdown in economic activity, also saw many countries - even European countries such as Italy - scale down their pledges to invest in renewable energy and to reduce their CO_2 emissions. Clearly, the fear of high costs is real and could threaten the political will to transform the energy system.

To understand the issue of costs, however, it is important to understand how costs are estimated. The earliest integrated climate policy models, developed in the 1990s, took the relative prices of different technologies as a given - not affected by policies specifically designed to reduce reliance on fossil fuels - and also assumed that the current energy system of the day was by and large efficient. Hence, any switch from fossil fuels to an alternative energy source was assumed to be expensive and to remain expensive in the future. The models estimated the costs of even small reductions of greenhouse gas emissions to be in excess of 10% of GDP[96-97].

The next generation of integrated models, developed around 2000, moved away from an assumption that technology price differentials are fixed. They incorporated the assumption that the price of technology falls, the more investment goes into it, meaning that policies encouraging renewable energy development would also make renewable energy less expensive[86, 98-99]. These models, the results of which formed the basis for the Stern Review and 2007 IPCC 4th Assessment Report, suggested that the costs of major emissions reduction would be about 2% of GDP[81, 99].

While this may still sound like a lot, it quickly seems trivial when placed in the context of economic growth. Assuming that GDP is itself growing at an average of 2% per year, the economic cost of fixing climate change would simply be to delay by one year - such as from 2050 to 2051 - arriving at any given wealth level which would, in any case, be a level much higher than today's. The most recent generation of models go one step further: they do not assume that the energy system of today is necessarily in an efficient equilibrium, meaning that policy may push the energy system towards a state that is both less expensive and lower in emissions. These models, in turn, suggest that particular technology-specific policies could result in both complete decarbonisation and greater economic growth[100].

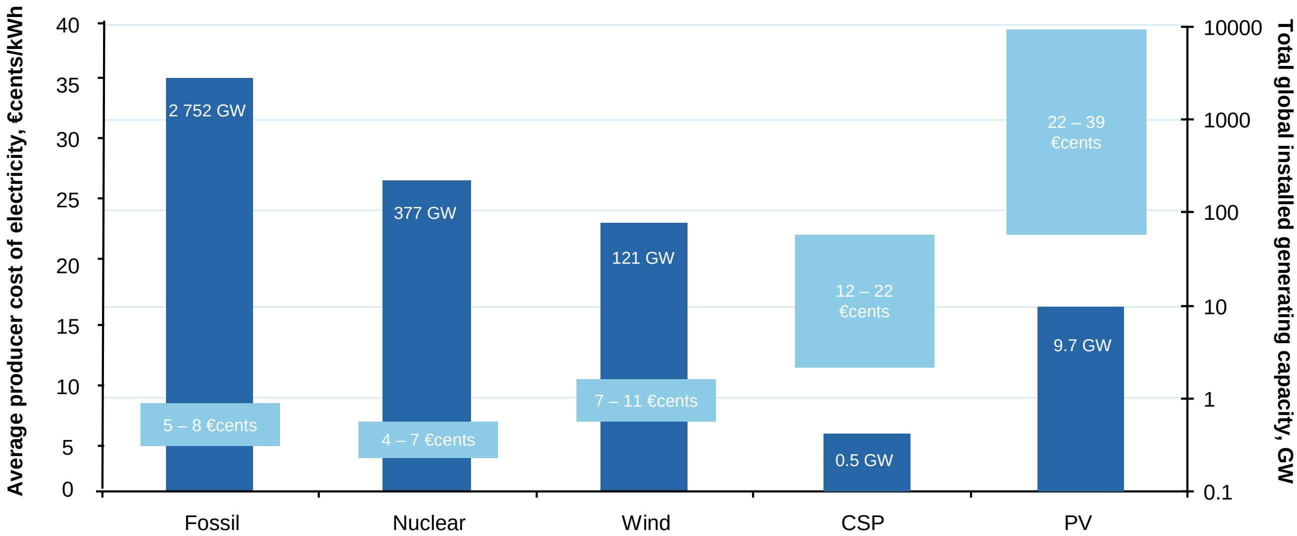

Figure 11: Relative costs and installed capacities of different technologies[37, 39, 79-85, 111-117]

Figure 11 illustrates typical current levelised generation costs, current installed capacities and the potential for generation cost reductions for the most common technologies, based on several data sources. The light blue bars represent the range of electricity costs for new installations, as of 2009, for a variety of technologies. But these costs can and will change. The dark blue bars indicate the total installed capacity worldwide.

The installed generating capacity scale is logarithmic therefore each space between the horizontal gridlines corresponds to just over a doubling of installed capacity. Hence, increasing installed capacity from one grid line to the next would be likely to result in a lowering of investment costs for that technology by about 10-15%[78]. This allows one to see that growing the capacity of wind to match that of nuclear will be likely to lower its range of costs to that of fossil fuels. Given that wind capacity has been growing at an average rate of 25% over the last 15 years, this is something that could easily occur in the next five or six years, should the current trend continue. It also suggests that growing the capacity of CSP to a quarter of that of wind today - doubling the installed capacity six times to about 32 GW – could well result in cost reductions of over 65%, making CSP the least-cost technology available.

There are two other interesting points to note from the figure. First, new investment directed into conventional fossil fuel technologies makes very little difference to their costs, simply because existing capacity is already so high but also because the share of capital costs in the fossil LCOE is much lower than for renewables. In contrast, renewables, except biomass, do not have any fuel costs. Second, the potential for PV to achieve a comparable cost range is not good, in the absence of a major technological breakthrough such as improvements in thin-film collectors or luminescent concentrators[98]. At ordinary learning rates, installed capacity would have to double about eight times for PV to become competitive with fossil fuels and this would require increasing capacity to an amount comparable with the entire current global energy system. While there may be other important reasons to grow PV, especially for off-grid applications, using it for on-grid bulk power generation is not one of them.

Two recent studies have addressed the question of how expensive it would be to increase capacity in CSP to become competitive with coal and gas. A 2008 study by the Center for Global Development examined the issue, assuming a set of baseline conditions that would act to lower the cost of CSP investment. They concluded that cost parity could be reached by 2020, with 20 GW of installed CSP capacity in North Africa. It would require US$20bn in state subsidies in order to stimulate private investment[85].

A later study completed in 2010 looked at a wider range of assumptions, including the cost of building a transmission line from North Africa to Europe. Under baseline assumptions and assuming that the costs for coal would not change from today's level, it concluded that CSP would be competitive for the European market by 2030 and would require €40bn in support[35]. Under more optimistic assumptions, it came to similar conclusions as the earlier 2008 study while, under more pessimistic assumptions, the time to cost parity would be pushed back another ten years and the total support required would exceed €100bn.

These cost estimates do not include the costs of additional and improved transmission capacity in Europe, to achieve a true SuperSmart Grid[17]. To achieve 100% renewable power generation, strong grid reinforcements both within Europe and within North Africa will be needed – linking the two regions will not be enough. The transmission will be the enabler of the transformation, and this new infrastructure will require significant investments over the coming decades. While there are several modelling teams in Europe currently examining the issue, there are not yet any estimates available as to the system requirements and the associated investment costs.

But, even if these costs were to push the €40bn baseline estimate over €100bn by 2030, this number is not large in comparison with existing investment levels or with the level of support for renewable energy that European countries have been providing. Germany has already put €40bn into support for wind and PV[65], while one of its leading power companies, E.ON, plans to invest €30bn mainly in transmission and fossil-fired generation capacities in the three years 2009-2011[86].

The most recent economic models show that the short-term costs of transforming the power system may not be very large. Indeed, once this transformation has taken place, a power system based on low-cost renewable technologies will be likely to be able to provide consumers with considerable - and growing - cost savings compared to a ‘business as usual’ approach. This will rely, however, on continued support for renewable R&D and the putting in place of risk reduction measures to lower the cost of project finance, ensuring that the actual costs are at the low end of the range of existing projections. Finally, there is also the important consideration of labour market and social costs and the need to consider measures to ease the transition for people and businesses in fossil-fuel industries, such as coal mining, which will be left behind in the move to renewable energy.

5.3. Environmental concerns

The world is full of examples where efforts to solve one problem have made another problem worse. A concern with the development of renewable energy is that, while it may solve the problem of climate change, it will have other environmental consequences that are equally serious. Windmills, after all, have been shown to kill birds, although a quantitative analysis shows that the numbers killed are orders of magnitudes smaller than those killed by automobiles, or housecats[2]. While more research is necessary, it does appear that the shift to renewable energy could also have substantial positive environmental consequences, primarily through the elimination of pollutants from coal power plants and internal combustion engines[101]. One issue that does stand out, however, is water availability.

Water and energy production are intrinsically linked; oil drilling and refining is a water-intensive process. Water is also used in electricity production, since most thermal power plants rely on a steam turbine cycle. In order to increase the efficiency of the steam cycle, it is necessary to cool the power plant. The most efficient way of doing so, from an energy and cost perspective, is to use additional water, either heating up an adjacent river or reservoir or by using wet cooling towers, which let off their heat in the form of steam. CSP has the same cooling needs, which becomes problematic given that the ideal climate for CSP is an arid one, meaning that water is already scarce.

Consider the country of Morocco, which has 29bn cubic meters of renewable fresh water per year[102]. This translates into 936 cubic meters per person, below the water poverty threshold (as set out by the United Nations Development Programme) of 1200 cubic metres. Currently, the country withdraws a small fraction of this, 88% of which is for agriculture, 10% for household use and 2% for industry. Operating 50 GW of base load (350 TWh/a) wet cooled CSP would consume about one billion cubic meters of water annually, equal to 3% of the available water resources or 35% of the water consumed in households. This water is there, but it is a sought-after resource for many basic uses. With dry cooling, the need for water would be reduced by as much as 99% [103] and, at a national scale, the water issue does not appear to be a problem. More detailed research is needed at the local level. Such research needs to include an examination of how climate change might affect water availability and how demographic and economic changes influence competing water requirements. Research is also needed to determine the feasibility of dry cooling especially at higher temperatures.

Making the desert bloom?

One potential solution to solve the cooling problem for CSP plants has been to locate them on the coast, where they could use seawater for their cooling needs. This offers the additional benefit of being able to condense the resulting steam, producing plentiful desalinated water as a by-product of electricity generation. A German report suggested that this could be a major added benefit for the North African region[104].

However, there are reasons to be cautious about this potential benefit. First, it is not clear whether it would be more efficient to use waste process heat from CSP plants for desalination or to use electricity produced by the plants for reverse osmosis. If the latter, then CSP plants present no obvious benefits over current sources of electricity, such as coal or gas, from a desalination perspective. Second, in many respects, the coastal areas may be less desirable for constructing CSP plants compared to inland sites. The coast tends to be hazier and cloudier than inland, effectively reducing the direct normal insolation. Additionally, the availability of low cost, flat terrain along the coast may be limited. It is wonderful idea but more research is necessary to investigate whether relying on CSP to provide low cost desalination is feasible.

5.4. Sustainable development

For decades, policy-makers assumed that if a country was rich in natural resources and it exported those resources, the country and its people would benefit. According to economic theory, scarce natural resources command a high market price, leading to significant profits associated with their harvesting and sale. Developing countries could use these profits to fund investments into broader economic development, making its local industries competitive, increasing employment and the quality of life for its citizens. In the 1990s, however, empirical research results began to upset this conventional wisdom, and economists began to speak of a ‘resource curse’[105], a topic still very much debated[106]. It appears that countries that rely on natural resource exports underperform their less well-endowed peers, with lower associated levels of human development. A major concern associated with the 2050 roadmap (in which North African countries would be developing their “solar resource” for export) is whether they would suffer as a result.

There are two sides to the resource curse. First, in a system of freely moving exchange rates, large export revenues have the effect of raising the value of the national currency. This makes imported goods less expensive. It is great for consumers of those imported goods but it is bad for local industries that compete against them or which are themselves trying to enter export markets. Indeed, the currency effects of the export revenues effectively prevent other industries, ones not already contributing to those exports, from developing. If exports are driven by a broad swath of industries, as they are in Germany or Japan, then there is little to worry about, since most workers are already participating to some extent in the export economy. Export revenues derived from natural resources, however, tend to dominate the balance sheets of many developing countries. The more they export, the more they come to depend on their natural resource exports and the more vulnerable their economies become to market volatility in resource markets.

The second side of the resource curse is governance. Resource-exporting countries that did not already have a strong tradition of good governance before their growth in resource exports are unlikely to acquire one after. The primary competition over natural resource extraction is not about technology, but rather about acquiring legal access to the resources, and this creates an opportunity for corruption. When government employees’ major income source is linked to the gifts they and their colleagues accept, then the overall quality of governance tends to fall, and with it the provision of basic government services essential to people’s wellbeing.

In North Africa, as in many developing countries and regions, the issue of the resource curse is compounded by a rocky history of colonisation. Following the difficult and often traumatic independence process, a series of lending practices of European and international organisations have led several North African countries into large amounts of debt. A precondition for this lending, and for assistance with currency fluctuations from the International Monetary Fund, was often the liberalisation of essential government services - such as education - in a process known as structural adjustment. There is strong evidence that this lending has hurt recipient countries[107].

Thus, it is by no means clear-cut whether European efforts to obtain renewable power from North Africa would bring sustainable development. What is clear is that attention to strong institutions in the region, and linking Europe to the region, will be key factors in whether development is sustainable and beneficial. In the case of CSP in the North Africa region, research is needed to identify whether the resource curse is indeed a threat to social and economic development in North Africa. If it is, then a great deal of policy makers' attention will be required to develop the institutions needed to overcome the resource curse challenge. The resource curse is not inevitable: countries with strong institutions in place, such as Costa Rica, have not suffered its consequences.

Four questions are particularly relevant for further research:

1. What is the potential of the project to offer not just short-term construction employment but also long term capacity development in the host country or community? For renewable power development in North Africa to contribute to the region's long-term economic development, it is essential that its primary benefits are not simply the revenue stream it generates but rather the skills associated with designing, operating, and maintaining modern industrial facilities and the business and employment opportunities associated with service and supply chain provision.

2. To what extent will the project leverage European investment to provide low-cost and reliable energy for the local community? The first priority for energy projects in North Africa is that they provide the power necessary to improve local people's lives, through rural electrification and more reliable access. Exports to Europe need to be in addition to this.

3. To what extent do local stakeholders - not just the government but also a wider range of civil society - have a role in determining the project's design, placement and operation? It is essential for new projects not to come at the cost of disempowering local people and groups.

4. What are the institutions in place to guard against corruption and deterioration of government accountability? There are a number of programmes already operating, such as the Extractive Industries Transparency Initiative, that address this issue and it is essential to incorporate them or build on their successes.

Projects that address these four issues have a high likelihood of delivering sustainable benefits to North Africa, avoiding the negative impacts often associated with resource extraction and export.

5.5. Addressing the global climate problem

This report focuses on decarbonisation in Europe but, of course, climate change is a global problem. Even if Europe decarbonises its power system, that alone will not halt climate change or even slow it down any considerable amount. By the end of the century, not just Europe but all countries will need to eliminate the CO_2 emissions from their energy systems, as well as the net emissions from other activities such as agriculture and forest management, if dangerous climate impacts are to be avoided[108].

Most people took it for granted that the global challenge of climate change requires a coordinated, global solution. The forum within which this solution could be negotiated has been the UNFCCC, in place since 1994. The first stage of the UNFCCC approach was the Kyoto Protocol, negotiated in 1997 and entered into force in 2005, and containing binding targets for industrialised countries over the period 2008-12. At the COP13 in 2008 in Bali, Indonesia, countries agreed to negotiate the next set of targets for the Kyoto Protocol, or another protocol to succeed it, by the 2010 COP15 in Copenhagen. Ultimately the obstacles to consensus were too great and negotiators failed to agree on a specific post-2012 Protocol.

What they did agree on - the Copenhagen Accord - was a strong statement of principles, including the need to limit climate change to no more than 2°C average warming, but did not contain any binding targets. Probably the most important barrier to consensus was the question of how much developing countries, including rapidly industrialising ones such as China and India, need to take a role in reducing their own CO_2 emissions. Given that the least expensive and most reliable forms of modern energy can still be obtained from fossil fuels, many people argued that efforts to reduce CO_2 emissions in developing countries would raise the costs of energy and interfere with the struggle to eliminate poverty and raise standards of living to acceptable levels.

A critical question, then, is the extent to which the regional approach to energy system transformation that we have developed here would hinder, or contribute to, a more general global transformation. The argument that it would hinder such a transformation rests on two basic arguments, one of them economic and the other political. The economic argument is that a regional approach relying on feed-in tariffs and other subsidies would hinder the creation of a global carbon market. That market, created by the Kyoto Protocol in the form of the CDM, funnels investment money from Europe to developing countries, where it supports the construction of renewable energy projects. By focusing on reducing its own emissions domestically, European countries would significantly reduce that market, and hence slow the spread of renewable energy into developing countries. The political argument is that achieving consensus on a global solution requires solidarity. If each region engages in its own solution, and those solutions differ, it will be even less likely that negotiators in the future will agree on a single, global framework.

But there are also strong arguments why the regional approach here would lead to a more rapid global transformation than would take place in its absence. Central to these is the power of investment to transform the relative prices of different technologies. As we have already stated, several recent studies demonstrate that investment in wind and CSP, at a scale consistent with the approach we have advocated in this report, would result in their costs falling to below those of fossil fuel technologies, within a time period as short as ten years from now. This would fundamentally transform the relationship between climate change mitigation and poverty reduction, from one in which the two goals are in conflict with each other to one in which they are aligned.

In such a world, countries will not reduce their emissions because a binding global treaty forces them to, but because it is in their own economic interest to do so. Fortunately, the particular renewable technologies that are suitable for Europe and North Africa are also suitable for the rest of the world. Neither the wind nor solar resources found in Europe and North Africa, nor the distances between those resources and the centres of demand, are unique to the region. Indeed, every continent has enough solar and wind potential, when coupled with hydro and other renewables, to meet its own power demand. The investment that Europe and North Africa make to achieve their 2050 energy and climate objectives would create the market conditions necessary for the rest of the world to follow suit.

6.

Conclusions and next steps

"The report is very timely. The success of this project requires unprecedented alignment of interests. It depends on planning that looks at the long-term and considers how the direct and indirect stakeholders can benefit. Collaboration between the public and private sectors in the various European and North African states at various levels will be essential to mitigate potential risks."

Lucian J. Hudson

Partner and Managing Editor, Cornerstone Global Associates
Former Director of Communication, FCO

6. Conclusions and next steps

There have been many previous studies demonstrating that renewable energy sources are abundant and sufficient to satisfy current and future electricity demands both in Europe and North Africa. In all cases, a SuperSmart Grid is a pre-condition for fully exploiting renewable energy sources where they are abundant and most profitable. This report has proposed that the electricity supply system of Europe and North Africa can be transitioned to one that is 100% renewable in 2050 if the right policy framework is put in place today to drive activity in the coming decades. Under the right conditions, with such a framework supporting the aims of government and industry, a transformation of the power sector can occur in parallel with the growth in electricity demand in both regions.

This transition will be invisible to consumers as it should be possible to deliver it without any changes in lifestyle being required or any changes from today's levels of power reliability. Behind the scenes, the grid architecture, however, will have to expand and develop substantially over time to allow for the necessary levels of trade between the two regions and the geographical optimisation of the power mix. Other changes needed include the adoption of longer term (post-2020) cross (national) border planning horizons and a step up in the role of a central entity, like ENTSO-E, to oversee the strategic planning at European level. As part of this, there will be a need to include the option of considerable electricity trade and imports from North Africa and the imposition of stricter renewables targets for 2050.

While the vision may be ambitious, what is encouraging is that the business community has already developed a number of solutions to address energy security, energy prices and climate change. A variety of technologies with different characteristics and potentials are already available to be deployed at scale now so the ingredients discussed in this report should not be considered radical. Through the use of existing renewable technologies with storage capabilities, the need for back-up capacity will be reduced as will possibly true electricity prices for consumers. However, to get these developed to a point where they have an EU-NA regional impact, will, as mentioned above, require that governments provide the leadership and deliver longer term confidence and clarity for investors through the development and implementation of clear government policy. Building on existing political processes and bundling these in a new way is perhaps slightly radical, although not impossible. Once in place, these can then influence the power sector to effect the changes needed across industry and society.

As we outline in our roadmap chapter, developing the appropriate government policy to manage this transition should take into account a number of key attributes such as longevity, certainty, transparency and cost. Policy development to support a transition to the 2050 end state proposed by this report will be further complicated by having to consider the impact of other areas of the power system model, in particular the challenge of managing supply and demand for power in the face of increasing fluctuation of supply, the issues of infrastructure siting and planning, an effective system for putting a price on carbon and the phasing out of fossil fuel subsidies.

On one hand, this may look like a long list of challenging areas that need to be addressed to make progress with the transition proposed. On the other hand, this report has outlined how they can be more easily addressed if considered as part of a coordinated whole. The use of a simplified power system model indicates how efforts could be coordinated and how solutions in one area can resolve issues in another area. In addition, the case studies in Appendix 4 show how governments and business have successfully worked together in the past to overcome similar challenges. Indeed, many of the elements of what we propose already exist or are being planned.

Looking ahead at next steps, this report has highlighted a number of areas that require further investigation to provide the detail that is needed to deliver this transition. Further details are included in Appendix 5, but some of the key questions that will need to be answered include:

Government policy

- What is the right timeline for considering significant exports of electricity from North Africa to Europe?
- What are the policy steps Europe needs to make in order to support current exporters of fossil fuels during the transition phase?

Investment and finance

- What are the best financial instruments for channelling investments into renewable generation and transmission capacity?
- What are the business models for exporting electricity within and between Europe and the North African region? What is the scale and the risk of the required investment in comparison to gas investments?

Market structure

- Is it necessary to have one single market, or would a number of regional markets be sufficient to realise the required competitiveness and pricing optimisation?
- What is the right level of regulation? Do we need a regulated or deregulated market?
- What governance structures need to be implemented?

Infrastructure and planning

- What is the required transmission capacity that needs to be put in place to guarantee the same level of reliability as in Europe today? What is the grid architecture that needs to put in place in order to have a 100% renewable power sector?
- How feasible is a full scale offshore grid and what would it cost? Is there enough capacity to satisfy growth? How can supply chain bottle necks be overcome?
- What level of back-up capacity is required over time and what role can demand side management really play at a national and European level?

As mentioned at the start, we have developed this report in the hope that it will contribute to the development of new solutions to meet our upcoming energy and climate change challenges. Presenting the achievement of the 2050 vision in the form of a roadmap has been purposely done to provide a template and framework for engaging with a wide range of stakeholders.

The roadmap approach should also support the holistic identification of areas where additional work will be required and most importantly, by breaking down what seems impossible today into manageable steps, encourage us to be ambitious in our vision. We believe that, if supported by the necessary political will and leadership over the long term, and the development of detailed underlying plans, the roadmap approach will provide a useful basis to support our transition from today’s starting point to the 2050 vision proposed by this report.

7.

Appendices

Appendix 1: Acronyms and glossary

Appendix 2: The 2050 roadmap in detail

Appendix 3: Cost calculations and assumptions

Appendix 4: Case studies

Appendix 5: Taking the roadmap forward – additional study areas

Appendix 6: References

Appendix 7: Contact information

Appendix 1: Acronyms and glossary

Acronyms

Acronym	Explanation
ACER	Agency for the Cooperation of Energy Regulators
CCS	Carbon capture and storage
CDM	Clean development mechanism
COP	Conference of the Parties to the UNFCCC
CSP	Concentrating solar power
DII	Desertec Industrial Initiative
DSO	Distribution system operator
EMU	Economic and Monetary Union
ENTSO-E	European Network of Transmission System Operators – for Electricity
EU ETS	European Union Emission Trading Scheme
EU	Unless specified (e.g. EU-27), we have used EU interchangeably with Europe to represent all present and potential future European Union Member States
EUA	EU Allowance (as used in the EU ETS)
EU-NA	Europe and North Africa
GDP	Gross domestic product
GEF	Global Environment Facility
GWh	Gigawatt hour
HVDC	High voltage alternating current
HVDC	High voltage direct current
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change

Acronym	Explanation
IRENA	International Renewable Energy Agency
JI	Joint implementation
kWh	Kilowatt hour
LCOE	Levelised cost of electricity
MDB	Multilateral development bank
MEF	Major Economies Forum on Energy and Climate
MSP	Mediterranean Solar Plan
NA	North Africa
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaic solar power
R&D	Research and development
REEEP	Renewable Energy and Energy Efficiency Partnership
REN	Renewable energy
SEGS	Solar Energy Generating Systems
SET	Strategic Energy Technology (Plans)
SSG	SuperSmart Grid
TSO	Transmission system operator
TWh	Terawatt hour
UCTE	Union for the Coordination of Transmission of Electricity
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Glossary Term	Explanation
Base load	The minimum amount of power that a utility or distribution company must make available to its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements.
Dispatchability	The ability of sources of electricity to be dispatched at the request of power grid operators, i.e. to be turned on or off at on demand.
Electromobility	The electrification of transportation through the use of hybrid electric and all-electric vehicles instead of petroleum vehicles. Generally includes trains and road transport.
Europe	Unless specified (e.g. EU-27), we have used Europe interchangeably with EU to represent all present and potential future European Union Member States
Feed in tariff	A government-set rate that utility companies pay for 1 kWh of renewable electricity fed into the electricity grid by ‘third parties’ (private investors including households).
Grid parity	The situation where the generation cost of electricity is equal to the price of electricity in the market, including grid fees and taxes, at the point of connection.
Horizontal integration	Companies who are active in a number of different generation technologies.
Insolation	The measure of solar radiation received on a given surface area of the Earth at a given time.
Levelised cost of electricity	The cost of generating electricity for a particular system. It includes all the costs over its lifetime (typically 20-30 years) including initial investment, operations and maintenance, cost of fuel, cost of capital.
Levelised transmission cost	The whole life cycle costs of transmitting electricity.
Liberalised market	A market in which every customer has the right to procure electricity from an electricity provider of their choice and network operators are legally obligated to grant network access to all authorised producers and customers
Meshed grids	A highly interconnected transmission and distribution grid.
North Africa	The five countries in the north of Africa: Morocco, Algeria, Tunisia, Libya and Egypt.
Peak load	The maximum energy demand or load during a specified time period.

Glossary Term	Explanation
Reserve capacity **(spinning reserve, non-spinning reserve)**	The generating capacity available to the system operator within a short interval of time to meet demand in case a generator goes down or there is a disruption to the normal supply. Spinning reserve is the extra generating capacity that is available by increasing the power output of generators that are already connected to the power system. Non-spinning reserve is the extra generating capacity that is not currently connected to the system but can be brought online after a short delay.
Smart Grid	A grid which uses digital technology to deliver electricity from suppliers to consumers. The technology interacts with consumer appliances (business and residential) to save energy, reduce cost and increase reliability and transparency.
Subsidy **(implicit and explicit)**	A form of financial assistance paid to a business or economic sector, often to encourage it to undertake certain activities. An explicit subsidy is directly giving a business money to do something, while an implicit subsidy is giving them some other benefit which is equivalent to giving them money.
Super Grid	A wide area transmission network that makes it possible to trade high volumes of electricity across great distances. HVDC technology is typically used.
SuperSmart Grid	A hypothetical system which would unify Super Grid and Smart Grid capabilities and technologies into a comprehensive network. Envisaged to connect Europe with northern Africa, the Middle East, Turkey and the IPS/UPS system of CIS countries.
Synchronous grid	A power grid at a regional scale or greater that operates at a synchronised frequency and is electrically tied together during normal system conditions.
Unbundling	Uncoupling the electricity sector by ensuring the companies controlling the transmission networks are independent of the companies responsible for production and supply side activities.
Vertical integration	Utilities companies who are active in some or all aspects of the power market, i.e. generation, transmission, distribution and retailing.
Virtual power plant	A virtual power plant is a cluster of distributed generation installations which are collectively run by a central control entity.

Appendix 2: The 2050 roadmap in detail

Enabling area 1: Government policy

Milestone	Detailed enabling area activities	Cross-area dependencies
2010 **Current state** EU Renewables and Climate Directives, and EU ETS National energy policy and REN targets in EU and NA No unified NA policy, instead individual country level targets of varying levels of ambition NA Free Trade Agreement with EU in place under the Barcelona Treaty	**European Union** • The EU renewables directive (2009) stipulated that the EU should reach 20% renewable energy by 2020. It also allowed for electricity imports from non EU countries. • The EU ETS is currently in place, with further developments planned to expand the system. • National renewable energy targets, incentives and support schemes have been introduced in a number of Member States to promote renewable energy across the EU. Individual country Renewable Energy Action Plans are due for submission in June 2010. • Various other initiatives and frameworks to support the development of a 100% renewable power market are in place / underway e.g. EuroMed Partnership, EU Neighbourhood Policy, the Barcelona Process/Union for the Mediterranean, the Third Energy Package, the Treaty of Lisbon (especially Article 194) and others. • In December 2009 a pledge was made at COP 15 of $100bn from developed countries to support developing countries. **North Africa** • There has been progress in establishing renewable energy agencies in most countries. • There are national renewable electricity targets and policy in place or underway in most NA countries. • There has been the development of some renewable energy action plans (especially wind and solar) by some NA countries. There is no single unified NA policy; instead there are individual country level targets of varying levels of ambition. • There are a number of mechanisms available (e.g. CDM / JI) available to promote renewable electricity.	

<table>
<tr><th>Milestone</th><th>Detailed enabling area activities</th><th>Cross-area dependencies</th></tr>
<tr><td rowspan="2">End-2010

Short term milestone

Development of REN agencies and policies in NA

Analysis of the National Renewable Energy Action Plans submitted by EU counties to identify renewable trajectories</td><td>European Union
Individual country progress towards agreed EU targets is reviewed: GHG emissions 20%, Renewable energy 20%. Discussions continue on increasing the 2020 targets further and discussions on 2030 targets are started: GHG emissions 50%, Renewable energy 50%.
Renewable Energy Action Plans and long term support schemes / incentives across EU are reviewed. Work is underway to consider how these can work together as part of an integrated plan (EU Policy Plan) and to identify gaps and other activities needed to accelerate massive renewables deployment. The interaction of solar / renewables with other non renewable schemes and other national policy frameworks is also reviewed. A timeline to phase out all fossil fuel support schemes / subsidies by 2020 is agreed.
The proposed outcomes / outputs of the Solar Plan of the Union of the Mediterranean (and other renewable and grid initiatives e.g. DII and MEDRING) to date and plans for the years to 2020 are assessed. The approach to integrating these initiatives into a single EU plan that also considers the other activities underway is agreed.
Existing demand side management arrangements are reviewed; other large energy consumers that this could apply to in the short term are identified.
The need for additional specific installation targets for solar energy (PV and CSP) in the EU is considered to enable these technologies to “catch up” with other more mature renewable energy forms.
An approach to EU-wide incentives to reward installation of storage capacity, the provision of firm and dispatchable electricity and for system services is discussed.
The progress of the proposed EU electricity labelling directive is reviewed (Directive 2003/54/EC). This is used to encourage the development of standard green power purchase agreements. Private / national schemes / pilot projects in the interim if progress is likely to be slow on EU-wide activities are proposed.</td><td rowspan="2"></td></tr>
<tr><td>North Africa
The establishment of renewable energy agencies in countries (if not already in place) is encouraged; commitment to development of renewable energy, export potential and development supporting plans is discussed.
Progress already made in developing / integrating renewable energy plans in NA countries and grid infrastructure development is understood. Begin / review the development of national renewable energy policies.
Best practice is shared and alignment on approach to encouraging development of grid and renewable energy infrastructure is encouraged.
Identification of the necessary steps to achieving a wider regional NA energy policy is started.</td></tr>
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Milestone	Detailed enabling area activities	Cross-area dependencies
2012 **Short term milestone** Successful national bilateral policy negotiations regarding electricity export between NA and EU Release of technical guidelines on the implementation of Article 9 (electricity imports) of the REN Directive Learning from REN and FF support schemes in the EU National planning and permitting regulations for infrastructure simplified Planning of EU Directive on Grid Regulation which mandates long term EU planning	**European Union** • The outcomes of the 2010 EU activities above are consolidated into a single integrated policy plan (EU Policy Plan) to 2050. The additional policies, incentive schemes that need to be introduced are outlined e.g. policy options that reward the e.g. the amount of renewable electricity fed into the grid rather than installed capacity. The 2050 targets are taken into account in developing the policy plan. This plan is shared with NA countries as part of wider bilateral discussions. • Pilot projects (and support needed) that will illustrate the way in which imports from NA will interact with the proposed EU incentive schemes are identified. Guidelines that support the implementation of Article 9 of the REN directive for electricity imports from NA to EU are issued. • The way in which national EU support schemes will interact for intra EU exports / imports e.g. wind from UK to Germany are clarified. Requirements for further legislation that may be needed are agreed. Learning from the best EU support schemes has been applied across the EU. Inefficient support schemes have been phased out. • Work starts on the development of an EU directive on grid regulation which mandates long term EU planning. • The effectiveness of the EU ETS is reviewed with respect to driving down CO_2 emissions and the development of renewable energy energy policy and the introduction of new carbon taxes in member countries e.g. France and Ireland. The need for the extension of a carbon tax across the EU is considered. • The introduction of EU-wide incentives to reward installation of storage capacity, the provision of firm and dispatchable electricity and for system services begins. • The development of legislation to support the simplification of planning and permitting activities across the EU begins. • Approaches that could be used to support the direct marketing of renewable energy are developed. • Further encouragement for the rollout of existing demand side management arrangements, identify other large industries, companies that this could apply to in the short term is provided by governments. Additional policies and incentives are identified to support further take up of demand side management initiatives by business and residential users.	
	North Africa • A regional meeting of the renewable energy agencies (and IRENA) is arranged to review the outcome of the renewable energy strategies / plans / roadmaps for NA. Review the first draft of a NA policy and energy Plan. • Common approaches to support the ongoing development of regional energy policies and assessment of regional opportunities are identified.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	• A model to agree the proportion of electricity that will be exported or used domestically to support business and economic development in the coming years is proposed. • The development of incentive schemes to support renewable energy in NA begins. • The role that other initiatives can play to help "push" the development and installation of renewable energy in NA is identified and agreed.	
2015 **Short term milestone** EU climate and energy targets for 2030-50 set to inform strategic planning process Technical guidelines on implementation of Article 9 transposed into EU national legislation. Planning and permitting regulation transposed into EU national legislation EU Directive on Grid Regulation in place Development of institutional capacity in NA EU and NA ratify a Free Trade Agreement for electricity trade	**European Union** • Progress towards agreed EU targets is reviewed: GHG emissions 20%, Renewable energy 20%. Work continues on developing 2020 – 2050 targets. This is used to deliver a rolling 10 year EU Policy Plan to 2050. Development / discussions begin on a new EU REN directive and a new climate directive to take effect from 2020. The impact of NA policy plan is considered and how this could best be integrated with the EU one. • EU directive on grid regulation is in place. • Discussions begin on the approach to decommissioning existing generation plants. • Within the EU, additional feed in tariffs (supplemented by investment subsidies or other support mechanisms if needed) are introduced e.g. for southern EU countries to support solar and other renewable energy (as appropriate) rollout and encourage increases in installed capacity. • Further legislation is introduced (as needed) to support the existing EU directive and strengthen the provisions for electricity imports from NA to EU. Technical guidelines etc are transposed into national legislation. The activity is supported by the agreement of a Free Trade Agreement for electricity trade. • The early impact of the single EU-wide cap on CO_2 emissions (in place since 2013) covering power generation, energy intensive industry and aviation is analysed. 60% of allowances are auctioned. • The effectiveness of demand side management initiatives by business and residential users is understood. • Best practice planning and permitting regulations are transposed into national legislation. • The introduction of EU-wide incentives to reward installation of storage capacity, the provision of firm and dispatchable electricity and for system services is completed. **North Africa** • Further institutional capacity is in place across NA and used to support discussions around the development of a possible NA Policy Plan. This is used as a blueprint for the coordinated introduction of renewable and non renewable energy policies across NA.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	• Initial incentive schemes for renewable energy are introduced. • The development projects that can benefit from domestic electricity production e.g. desalination are identified. • The development of support schemes for mini grid and off grid applications (vs. grid extension) for NA countries are considered and agreed.	
2020 **Medium term milestone, linking with EU 2020 targets** New REN and Climate Directives mandating post 2020 targets in place EU 2020 targets met: 20% REN and 20% reduction in GHG's	**European Union** • The achievements against agreed EU targets are reviewed: GHG emissions 20%, Renewable energy 20%. 2030 targets are set and agreed: GHG 50%, renewable energy 50%, 2040 targets: GHG 70%, renewable energy 80%, 2050 targets: GHG 90%, renewable energy 100%. • A new EU REN directive (that includes generation targets) and a new climate directive mandating post 2020 targets as above is implemented. Transposition of directives into national legislation is completed. Ongoing review and updating of a rolling central EU 10 year policy plan that considers 2050 targets as end goal is underway. • Further changes needed to long term support schemes across EU following changes proposed in 2010-2012 are completed. Gaps, and activities needed to further support deployment activities are identified. The interaction of renewable with other non renewable schemes and other national policy frameworks is reviewed. • A coordinated strategy for the decommissioning of existing fossil fuel generation plants is developed and piloted. • The EU directive on grid regulation is implemented. • The support schemes for onshore wind across the EU decrease, or are removed if wind is already cost competitive. Governments look to start reducing direct and indirect subsidies for fossil fuels across the EU. • Emission limits on new fossil fuel generation plants are introduced – 500 g/kWh to encourage a reduction in new build activities and improved environmental impact for remaining capacity. • Increasing demand side management requirements for business and residential users are introduced.	

Milestone	Detailed enabling area activities	Cross-area dependencies
Development of post 2020/25 NA REN targets Coordinated strategy for decommissioning of EU FF plants begins to be drafted EU Directive on Grid Regulation implemented Increased alignment in EN and NA energy policy	**North Africa** • The institutional capacity in NA continues to develop as renewable energy programmes of work start to deliver. • There is increasing alignment between EU and NA energy policy. • The development of post 2020/25 renewable energy targets begins. • There is clarification on the role that SUSEA, ISES and others can play to help “pull” the availability of renewable energy from NA to other sub-Saharan African countries. • The construction of development projects begins e.g. desalination plants. • Feed in tariffs (supplemented by soft loans and investment subsidies where needed) are in place and working for North African countries.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2030 **Medium term milestone** EU 2030 target: 50% REN, 50% reduction in GHG emissions NA 2030 REN targets Strategy for decommissioning of EU FF plants implemented nationally	**European Union** • Achievements against agreed EU targets are reviewed: GHG emissions 50%, Renewable energy 50%. • Phasing out of selected renewable energy subsidies and incentive schemes for mature renewable energy technologies begins. • Implementation of a new EU REN Directive and a new climate directive to 2040 takes place. • 100% of EU CO_2 emission allowances are auctioned (since 2027). • The decommissioning of end of life fossil fuel generation plants is underway and continues in the period to 2050. • Increasing demand side management requirements for business and residential are introduced. • There is a further restriction on emission limits for new fossil fuel generation plants – 0 g/kWh to encourage a reduction in new build renewable energy activities and improved environmental impact for remaining capacity. **North Africa** • The achievement of post 2020 renewable energy targets is reviewed. Post 2030 targets are set. • The development of first round development projects is completed e.g. desalination, alignment of government and society to develop a second round of projects continues. • Possible sub-Saharan renewable energy links / projects are identified including the development of the business case, funding sources, government policy and support required.	
2040 **Long term milestone** EU 2040 target: 80% REN, 70% reduction in GHG emissions NA 2040 REN targets	**European Union** • Achievements against agreed EU targets are reviewed: GHG emissions 70%, Renewable energy 80%. 2060 – 2100 targets are set. • The phasing out of selected renewable energy subsidy and incentive schemes for mature and maturing renewable energy technologies continues. • Implementation completed of a new EU REN directive and a new climate directive to 2050. • Increasing demand side management requirements for business and residential users continues. **North Africa** • The achievement of post 2030 renewable energy targets is reviewed. Post 2040 targets are set.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	• The development of second round development projects is completed e.g. desalination, alignment of government and society to develop a third round of projects continues. • Necessary sub-Saharan government policies and support are in place to support proposed energy link projects.	
2050 **Long term milestone** **Final state** EU 2050 target: 90% reduction in GHG emissions EU and NA 2050 target: 100% REN	**European Union** • An aligned EU-NA energy policy is in place. • Achievements against agreed EU 2050 targets are reviewed: GHG emissions 90%, Renewable energy 100%. • Phasing out of all renewable energy subsidy and incentive schemes has been completed. • Implementation complete of a new EU REN directive and a new climate directive to 2100. • Increasing demand side management requirements for business and residential users introduced.	
	North Africa • Achievement of post 2040 renewable energy targets reviewed. Post 2050 targets reviewed. • Development of third round development projects completed e.g. desalination, alignment of government and society to develop a fourth round of projects continuing. • Necessary sub-Saharan government policies and support in place to support proposed energy link projects. • Development of regional sub-Saharan government policies and support to support further renewable projects underway.	

Enabling area 2: Market structure

Milestone	Detailed enabling area activities	Cross-area dependencies
2010 **Current state** EU market formally liberalised. Predominantly national, with 1 coupled and 1 international market NA markets national and not liberalised EU: Unconditional priority feed in for REN	**European Union** • The EU is formally a unified electricity market but it operates largely as fragmented into national markets. The Nordic market is the only international power market. • The European power markets are dominated by a few national, often vertically integrated giants. • Most Member States have unconditional priority feed-in for renewable energy. **North Africa** • There is an emerging focus on renewable electricity and the set up of renewable energy agencies. • The NA national grids are connected but not practically integrated. The NA markets are not liberalised.	
End-2010 **Short term milestone** Trend towards greater cooperation of EU markets	**European Union** • Agencies in each EU country that will coordinate engagement with the public on renewables are identified. • There is a trend towards greater cooperation of EU electricity markets. • A clear planning process for the EU power market is agreed. • Regular assessments of the progress made in unbundling the power market are completed. **North Africa** • Renewable energy agencies / government departments in NA continue to be established (with support as needed from MDB's, IRENA, etc). • The status of renewable energy policy development and application is reviewed.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2012 **Short term milestone** Trend towards greater cooperation of NA markets Research into a financial mechanism to reward dispatchability in REN	**European Union** • The legal frameworks in place to support the introduction of renewable energy in each country are reviewed, in particular in relation to legal certainty to support investments. • Agreement is obtained from member countries on a clear approach to the planning process for the EU power market on a regional basis. • MoU's are put in place between a number of EU and NA countries to support the development of HVDC cable links and the trade in electricity. • The EU carbon market develops further, with a realistic price for carbon. The EU drives the establishment of a global carbon market. • Research what financial mechanisms could be developed to reward renewable energy dispatchability is completed. • IRENA/equivalent agency is available to support the EU and NA infrastructure development plans for the coming decades.	
	North Africa • The establishment of renewable energy agencies / government departments in NA progresses. These are used to drive the development of renewable energy plans, and design of support schemes. The status of in country permitting institutions is reviewed. • There is a trend towards greater cooperation of NA markets and establishment of MoU's with EU Member States. • Opportunities are identified for the development in the in-country judicial systems, intellectual property rights and investment structures to support grid and renewable project investment. A comparison with minimum standards required by investors and technology companies is completed, and ways to address these by 2015/2020 are identified. • Other capacity building efforts required to address technical and administrative knowledge gaps are identified.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2015 **Short term milestone** Emergence of a number of regional markets in EU Removal of unconditional priority REN feed in to grid to avoid negative prices Real time pricing begins in the EU with the use of Smart metering	**European Union** • Adjacent electricity markets are linked to manage large renewable contribution to power system. Emergence of a number of regional markets in the EU. • Guidelines are issued to determine the appropriate allocation of network connection costs for new renewable capacity (project or operator). • TSO's are mandated to give priority or guaranteed dispatch to all renewable energy (provided that grid stability is not jeopardised) subject to agreed renewable energy power curtailments. Removal of unconditional priority renewable energy feed in to grid to avoid negative prices. • Real time pricing begins in the EU with the use of Smart metering. • Energy efficiency activities are underway, early savings are being realised. • There is good progress towards the establishment of a "green" job market and industry across EU. **North Africa** • Additional measures are introduced to address judicial issues. • Several NA power markets are linked. Blueprints for a regional NA market are developed. • Some early exports of electricity to EU are underway.	Smart technologies begin to be introduced in EU
2020 **Medium term milestone, linking with EU 2020 targets** Single EU regional market in place, no more national markets	**European Union** • Initial steps to connect regional EU-NA markets are underway. • All national markets have been unified with at least one neighbouring market. No strictly national markets exist. • Renewable energy prices and support schemes available in the EU market include mechanisms to reward dispatchability. • There is ongoing development of a "green" job market and industry across the EU. • The achievement of EU 2020 targets leads to recommendations for further changes to the EU market to support 2030 etc targets. **North Africa** • Final measures to address judicial and intellectual property rights issues are introduced	

Milestone	Detailed enabling area activities	Cross-area dependencies
Emergence of regional markets in NA REN prices and support schemes include mechanisms to reward dispatchability	• Regional NA power markets are emerging. • Early exports of electricity to EU are underway • Early development of a "green" industry and direct and indirect job market for NA	
2030 **Medium term milestone** Single EU regional market has initial connections to NA	**European Union** • The single EU electricity market now well established. • Steps to connect EU-NA markets continue – unification is aided by the multiple HVDC cable links now in place. • There is further development of a "green" job market and industry across the EU. • Achievement of EU 2030 targets leads to recommendations for further changes to the EU market to support 2040 etc targets. **North Africa** • All NA national grids are strongly interconnected – this supports the creation of a regional market. • Exports to EU continue, balancing domestic demands with export revenues. • The development of a "green" industry and direct and indirect job market for NA continues.	Increased alignment in EN and NA energy policy
2040 **Long term milestone** Full connection of regional EU market with regional NA market	**European Union** • Final steps to connect EU-NA markets underway – partial unification of markets. • A robust "green" job market and industry now exists across the EU. • Achievement of EU 2040 targets leads to recommendations for further changes to the EU market to support 2050 etc targets. **North Africa** • There is a single regional NA market. • Exports to EU continue on a larger scale, balancing domestic demands with export revenues. • The development of a "green" industry and direct and indirect job market for NA continues.	Considerable electricity exports from NA to EU begin

Milestone	Detailed enabling area activities	Cross-area dependencies
NA electricity export to EU balances national demand with export revenue	• Discussions start on the possible integration of the NA power market with Sub-Saharan markets.	
2050 **Long term milestone** **Final state** One unified EU and NA power market that rewards dispatchability	**European Union** • A unified EU-NA power market exists subject to common regulation. **North Africa** • Exports to EU continue on a larger scale, balancing domestic demands with export revenues. • The development of a “green” industry and direct and indirect job market for NA continues. • Discussions continue on the possible integration of the NA power market with Sub-Saharan markets.	

Enabling Area 3: Investment and finance

Milestone	Detailed enabling area activities	Cross-area dependencies
2010 **Current state** Nationally set support schemes for REN in EU of varying efficiency and effectiveness Limited and low investment in REN plants and R&D in comparison to nuclear and CCS	**European Union** • A range of nationally set financial incentives for renewable energy exist across the EU, of varying efficiencies, effectiveness and duration. • Investment levels in renewable energy R&D, demonstration and operational plants and HVDC are lower than that invested in e.g. nuclear and CCS. • The wider investor community is still wary of supporting large scale early investment in certain types of renewable energy infrastructure, even within EU boundaries. • COP15 results in a pledge of $100bn from developed countries for developing countries. **North Africa** • There is limited investor community appetite for renewable energy investment in NA even when linked to MDB programmes of work (EIB, WB CTF, AfDB etc.). • There is a requirement by MDB's to link development / investment funds for NA countries with the need to tackle energy reform.	

Milestone	Detailed enabling area activities	Cross-area dependencies
End-2010 **Short term milestone** Identification of funding channels, including funds from the EU Budget A standardised business case and financial model under development	**European Union** • More detailed information on true renewable electricity generation costs is developed and made available to the investment community. A rolling 10 year campaign starts to address perceptions within the investor community about supporting renewable energy projects and the development of local manufacturing capability. • National governments increase and coordinate public sector investments in R&D and deployments (including mechanisms that can provide equity and mezzanine capital to bridge the debt-equity gap). Public-public interaction is encouraged to support new renewable energy projects including identification of other funding channels and possible funding from the EU budget. • The wider financial community is engaged in the development of separate grid and renewable energy investment plans. The insurance sector is encouraged to provide further products that can de-risk renewable energy investment opportunities e.g. more comprehensive component insurance products. • Other risk mitigation mechanisms are identified that can make the financing of renewable projects more attractive to private sector investors e.g. public sector loan guarantees, credit enhancements. A standardised business case and financial model to support renewable energy investments is under development. • Utilities are encouraged to become more involved in financing renewable power projects. • Work is underway to better involve business end users in costs and financing of residential and commercial renewable electricity projects.	
	North Africa • Renewable energy incentive system plans begin to emerge in NA. • Public-private partnerships are established to accelerate investment in NA. • Further concessional financing is identified and made available to support generation and transmission projects (from e.g. World Bank, EIB etc). • The success to date of CDM, Certified Emission Reduction certificates to augment other local support schemes is reviewed and recommendations on how to improve effectiveness are made. • Specific funding for the first HVDC link between NA and EU is identified.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2012 **Short term milestone** Public-public and public-private partnerships established Concessional financing from development banks	**European Union** • Discussions about the 2014-2020 budget focus on renewable energy infrastructure project opportunities. • Plans are put in place to address how the COP15 pledge of $100bn from developed countries for developing countries should be deployed. • The 10 year campaign to address perceptions within the investor community about supporting renewable energy projects continues. • Separate grid and renewable energy investment plans are now in place leading to an increase in the amount of funding available and coordination of public sector investments in R&D and deployments. • Further risk mitigation mechanisms are identified. • More utilities become involved in financing renewable energy projects, more end users become involved in supporting the case for renewable energy projects. • The options for meeting the costs of upgrading grids within appropriate framework conditions across a number of countries is reviewed, recommendations are made. • Additional global partnerships (GEF, REEEP etc) are identified that could provide additional interest free loans, risk sharing and co-funding for renewable projects. Public:public and public:private partnerships are established where appropriate to take renewable energy investment forward. • Further innovative financing models / structures to support larger scale investment in renewable energy and grid in EU and NA are developed. Additional 3rd party financing models based on experience in Spain and elsewhere are identified and taken forward. Additional concessional financing is made available by MDB's. • The ability of public funding to pay for grid connection to new renewable generation facilities is reviewed. • Policy development focussing on internalising all external costs for all energy technologies begins to create more of a market pull. • There is an insurance industry wide initiative to identify / develop insurance products that can further de-risk the component, operational risks for investors. • Early energy efficiency savings are now being realised. Financial benefits where possible, are being captured for reinvestment.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	North Africa • The outputs from the regional meeting of the renewable energy agencies (and IRENA) are used to consider how the creation of a regional power market could be encouraged. • Restrictions imposed by the investment community on renewable project funding in developing countries are removed. • Alternative financing models are considered e.g. the micro financing approach to financing local grid projects in NA. • Work completed with investment community to ensure that international funding schemes become more transparent and accessible.	
2015 **Short term milestone** Update EU (REN and FF) support schemes to make them technology specific and reflect technology maturity. Introduction of NA support schemes 1st phase funding in plan in place (public-private partnerships)	**European Union** • 2014 – 2020 EU budget is in place. This includes substantial support for renewable energy infrastructure projects. • The 10 year campaign to address perceptions within the investor community about supporting renewable energy projects continues. • Public sector investments in R&D and deployments increases and becomes more coordinated. • Further risk mitigation mechanisms are identified to support new renewable energy projects. • The involvement of utilities in financing renewable energy projects becomes more widespread. End users become more involved in renewable energy projects. • EU support schemes for renewable energy have been updated to make them technology specific and reflect technology maturity. Levels of fossil fuel and nuclear subsidies are reviewed and, where possible, reduced. • The development is complete of new innovative financing models / structures to support larger scale investment in all renewables and grid – they are being used to support long term investment in NA infrastructure. • Policies are introduced that internalise external costs for all energy technologies to create more of a market pull. • Insurance policies are now available as standard to support renewable energy project developers. • A standardised financial model is in use to support the first phase of renewable energy business case and investment decisions. • Energy efficiency savings are now coming through and available for reinvestment in renewable energy projects.	Learning from REN and FF support schemes in the EU Technical guidelines on implementation of Article 9 transposed into EU national legislation.

Milestone	Detailed enabling area activities	Cross-area dependencies
	North Africa • The first set of renewable energy incentive schemes is introduced in NA. • Private sector funding is in place to support 1st renewable energy generation plant in NA. • A further tranche of EIB, WB CTF funding is made available to support the next wave of renewable energy investment in NA. • A progress review is completed of MSP, DII, WB CTF programmes in NA.	
2020 **Medium term milestone, linking with EU 2020 targets** Fossil fuel subsidies phased out in EU Start phasing out support schemes as REN technologies mature 2nd phase funding plan in place	**European Union** • The need to continue with the 10 year campaign to address perceptions within the investor community about supporting renewable energy projects is reviewed; a further initiative is launched to address remaining areas. • There is now increased and coordinated public sector investment in R&D and renewable energy deployments. • Further risk mitigation mechanisms are identified and deployed. • Utilities are now financing a larger proportion of renewable energy projects. End user involvement in renewable energy projects continues to increase. • A review is completed to confirm the ongoing need / changes for policies that internalise all external costs for all energy technologies to create more of a market pull. • Onshore wind is now cost competitive, subsidies are removed. Fossil fuel subsidies begin to be phased out across the EU. • Further energy efficiency savings are now coming through and available for reinvestment in renewable energy projects.	
	North Africa • The first revenues from renewable energy electricity exports to the EU are available to NA countries. • Private sector funding is in place to support 2nd set of renewable energy generation plants in NA. Private sector funding is in place to support 1st round of development projects in NA. A further tranche of EIB, WB CTF funding is made available to support the next wave of renewable energy investment in NA • A progress review is completed of MSP, DII, WB CTF programmes in NA with recommendations for the coming programme of work.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2030 **Medium term milestone** Ongoing phase out of support schemes as REN technologies mature 3rd phase funding plan in place, largely for scale up of NA REN	**European Union** • Renewable energy is seen as a mainstream investment for the investor community. Risk mitigation mechanisms have been successful and are gradually phased out. • Utilities are now financing a larger proportion of renewable energy projects. End users are heavily involved in renewable energy projects. • Further energy efficiency savings are coming through, and they are now forming the base investment for new renewable energy projects. • CSP is cost competitive. Subsidies can be begin to be phased out for CSP and other established technology components and redirected into strategic R&D activity.	
	North Africa • Private sector funding is in place to support 3rd set of renewable energy generation plants in NA. • Private sector funding is in place to support 2nd round of development projects in NA. • A further tranche of EIB, WB CTF funding is made available to support the next wave of renewable energy investment in NA. • A progress review is completed of MSP, DII, WB CTF programmes in NA with recommendations for the coming programme of work. • Funding options for sub-Saharan renewable energy energy projects are identified.	
2040 **Long term milestone** Ongoing financing packages to support REN construction	**European Union** • Renewable energy is seen as a mainstream investment for the investor community. Risk mitigation mechanisms have been successful and continue to be phased out. • Utilities are now financing a larger proportion of renewable energy projects. End users now involved in all renewable energy projects. • Further energy efficiency savings are coming through, and they are now forming the base investment for new renewable energy projects. • Further renewable energy technologies become cost competitive and subsidies can be phased out.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	North Africa • Export revenues begin to pay off renewable energy development loans. • Private sector funding is in place to support 4th set of renewable energy generation plants in NA. • Private sector funding is in place to support 3rd round of development projects in NA. • Funding options for sub-Saharan renewable energy energy projects are identified and in place. Procurement has been completed, projects start.	
2050 **Long term milestone** **Final state** No financial support to any electricity generation and all REN is cost competitive	**European Union** • No financial support for any electricity generation is needed any more. • Renewable electricity is fully cost competitive and considered a mainstream investment opportunity.	
	North Africa • Export revenues now reinvested into further renewable energy developments in NA. • Investment requests for African projects now seen as mainstream by investor community.	

Enabling Area 4: Infrastructure and planning

Milestone	Detailed enabling area activities	Cross-area dependencies
2010 **Current State** EU and NA grids comprised of a number of separate synchronous AC blocks. Nationally optimised with grid congestion EU: 44% carbon neutral power, of which 15% is REN NA: 9% carbon neutral power, of which all is REN Very little use of smart technologies	**European Union** • The EU grid is composed of five asynchronous AC blocks with limited interconnections and grid congestion. • Grid regulation and planning at national level, based on medium-term economic efficiency. • The EU power supply is very reliable. • Many generation and transmission assets are approaching the end of their lifetime. • There is little or no use of Smart technologies. • 44% of the electricity comes from carbon neutral sources, of which 15% is from renewables and 29% from nuclear power. • There is priority access to the grid for existing renewable energy sources. **North Africa** • Some historical renewable energy infrastructure development underway in NA countries. • The NA power grids are physically but not practically interconnected. • 9% is carbon neutral power all of which is from renewables and predominantly hydro.	

Milestone	Detailed enabling area activities	Cross-area dependencies
End-2010 **Short term milestone** Nationally planned HV transmission and REN generation projects, many individual projects already in planning or under construction 10 yr rolling plan which identifies future transmission, generation and supply chain targets	**European Union** • Capacity planning by national states begins to feed into work led by ENTSO-E to consolidate existing information on EU grid infrastructure. This includes a review of the progress of existing HVAC, HVDC projects and system integration work. • ENTSO-E begins to develop plans for further anticipated European electricity network capacity development needed (HV) that takes into account a large future share of variable renewable energy. An integrated SuperSmart Grid plan is developed. This is in the form of a rolling 10 year plan that identifies future transmission, generation and supply chain targets and takes 2050 targets into account. • Projected cost parity timelines for all forms of renewables are developed and published. • An approach to improving and optimising existing grid infrastructure including connection of adjacent power systems and markets is agreed between ENTSO-E and other bodies. • ENTSO-E works with the EU / Member States to consider the need for Renewable Electricity Zones (or equivalent concepts) across the EU to allow prioritised construction of new HV grid links. • ENTSO-E works with EU to develop and agree common methods to assess costs, benefits and environmental impacts of grid infrastructure across the EU. • Existing nationally planned HV transmission and renewable energy generation projects continue to be planned / constructed. • There is improved EU-wide-area monitoring of power flows (and weather forecasts). This is introduced to anticipate congestion, demand and weather related issues. • Existing best practice permitting and approval procedures, lessons learned are identified and captured. The development begins of central knowledge hubs to support in-country permitting institutions and technology deployment. Joint capacity building activities and know how transfer mechanisms within the EU, and mechanisms for NA sharing are identified. • IEA Implementing Agreement structures to support greater technology cooperation between North:South countries in EU-NA are considered. **North Africa** • Discussions continue with governments and TSOs in NA on improving the interconnections between power systems.	EU Renewables and Climate Directives, and EU ETS

Milestone	Detailed enabling area activities	Cross-area dependencies
	• Support is provided by EU Member States to enable NA countries to develop common methods to assess costs, benefits and environmental impacts of renewable energy projects across NA. • Existing best practice approval procedures, lessons learned etc, and information that can be contributed to central knowledge hubs to support in-country permitting institutions and technology deployment is identified. • The need to introduce Renewable Electricity Zones is reviewed (to support NA infrastructure development and transmission lines). • Feasibility studies start to identify possible sites for renewable (esp. solar) projects. Detailed collection of on site solar radiation, wind data etc. starts.	
2012 **Short term milestone** ENSTO-E take on the role of overseeing strategic planning of SSG Smart technologies begin to be introduced in EU R&D into storage and flexible reserves Construction of nationally planned HV lines Regional planning of commercial scale demonstration plants and deployment plants for REN generation	**European Union** • Following the development of EU-wide HV plans, ENTSO-E takes on the role of overseeing the strategic planning of the EU SuperSmart Grid. It also takes ownership of development plans to extend and upgrade EU grid capacity. • The EU SET Plan programme assumes responsibility for planning the development and construction of renewable energy generation work. • Work by ENTSO-E to update the HV grid design for the EU continues. The approach and transition takes into account the fossil fuel industry concerns. • A mandate is issued by the EU to ensure that all new line upgrades make use of new line technologies that increase grid flexibility and that existing grid infrastructure performance is improved through optimised operation. • Further R&D and demonstration project work is completed to identify and support greater access and system integration for all renewable sources, and the further development of the Smart Grid. R&D also looks at opportunities for storage and flexible reserves. • Technologies / innovation that allow for higher amounts of solar electricity to be integrated by the market and system are encouraged. Smart technologies begin to be introduced across the EU. • Discussions on how flexible power plants and storage technologies can be integrated in to the EU-wide network start. Construction of nationally planned HV lines continues. Individual renewable energy projects (wind, solar etc.) continue to be constructed in Member States. • Effort continues to be spent on the identification of existing best practice approval procedures, lessons learned etc. Central knowledge hubs are now in place. Learning from best support schemes is shared and applied across the EU. • There is a regional planning approach to the development of new commercial scale renewable energy generation in the EU.	Development of REN agencies and policies in NA

Milestone	Detailed enabling area activities	Cross-area dependencies
	North Africa • Regional planning of commercial scale demonstration plants and deployment plants for renewable energy generation starts. Sites for the development of renewable energy component production facilities are identified. • The outcomes of the feasibility studies to identify possible sites for renewable (especially solar) projects are reviewed. The collection of solar radiation, wind etc data continues. • Information sharing begins to identify best practice approval procedures, lessons learned etc. Information that can be contributed to central NA knowledge hubs to support in-country permitting institutions and technology deployment is identified. • The planning / procurement of next wave of renewable energy generation plant construction begins. The construction of the 1st HVDC link to EU starts (Tunisia to Italy). Construction starts on the MDB funded CSP / PV projects. • Work continues to build a better and stronger AC grid across NA (computerised, automatic). • There is ongoing collection of solar radiation, wind data etc.	
2015 **Short term milestone** Strategic development plan for SSG and REN to 2050 Regional EU SSG (HVDC) initiatives underway	**European Union** • A review is completed to consider the success of the policy guaranteeing connection to grid schemes for solar and renewable projects. • A coordinated EU plan and strategy for the commissioning and decommissioning of fossil fuel plants is agreed by Member States. Target is to have no fossil fuel plants in operation by 2050. • The EU SET Plan and ENTSO-E plans to 2050 are integrated. There is signoff and agreement by EU-NA on the integrated SuperSmart Grid and Renewables work plans. Work begins to put in place the mandate that Grid Operators require to manage the new Super Grid. • Further construction takes place to extend and upgrade EU grid capacity, including continuous upgrading of HVAC links. It is now common practice that all line upgrades make use of new line technologies that increase grid flexibility and that existing grid infrastructure performance is improved through optimised operation. A review starts to look at how the EU HV grid system operation is able to cope with larger amounts of variable renewable power. • There are a number of regional EU Super Grid initiatives underway (North Sea, Baltic Sea, possibly the Mediterranean Sea).	Public-public and public-private partnerships established Concessional financing from development banks

Milestone	Detailed enabling area activities	Cross-area dependencies
Ongoing reinforcement of HVAC lines in NA and EU Construction of REN generation capacity to meet 2020 national targets	• A significant number of renewable energy projects (wind, solar etc) are under construction in Member States to meet 2020 targets. • The construction of the next set of pilot projects that will illustrate the way in which imports from NA will interact with the proposed EU incentive schemes is planned and started. • Best practice approval procedures, lessons learned now commonly used across the EU, driven by central knowledge hubs across EU and shared with NA.	
	North Africa • The first HVDC cable connecting NA to EU is in place. Further construction takes place to extend and upgrade NA grid capacity, including continuous upgrading of HVAC links. • NA has set up the appropriate organisations / structures to allow for the transfer of technology knowledge from the EU. • The first solar /wind demonstration projects are completed. Planning has been completed to support the establishment of next wave of demonstration and test sites in NA by EU companies. There is significant engagement with local government and business to support the feasibility and construction work. • Planning / procurement has been completed allowing construction of initial renewable energy (solar, wind) production facilities to start. Planning for the next phase of renewable energy projects starts and is linked to the expansion of the NA grid infrastructure. • In-country permitting institutions and knowledge hubs are now closely linked to EU knowledge hubs / institutions. • There is ongoing collection of solar radiation, wind data etc.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2020 **Medium term milestone, linking with EU 2020 targets** No new construction of coal plants Regional EU SSG initiatives in place. Smart technologies widespread. EU wide SSG emerging Large scale construction of REN generation capacity to 2020 national targets Early electricity exports begin from NA to EU	**European Union** • Construction programmes over the past 10 years have reached the goals of the proposed Renewable Action Plan technology and generation infrastructure. Offshore wind and other renewable energy now provide a significant portion of total electricity generation across the EU. • ENTSO-E uses the final HV grid design for the EU as a basis for further planning and development activity. A review is completed to understand progress and inform the plans to extend and upgrade EU grid capacity in the coming 10 years. The Grid Regulators and the mandate that they require to manage the new Super Grid are in place. • A significant number of renewable energy projects (wind, solar etc) are under construction in Member States. The EU plan is reviewed to address the need to replace aging generation infrastructure by 2040. • The regional EU Super Grid initiatives are near completion (North Sea, Baltic Sea, possibly the Mediterranean Sea). A start is made on the construction of an EU Super Grid using HVDC links in addition to existing HVAC networks. Smart technologies are now widespread. • The information obtained from the pilot projects to support the development of further programmes involving imports from NA and their interaction with the EU incentive schemes is reviewed and used to inform further projects. • There is a better understanding of how the EU grid system operation is able to cope with increased amounts of variable renewable power now connected to the grid. Action is taken to scale up the number of balancing power plants, storage technology that is in place to balance the increased renewable input. • Electromobility begins to take off in capital cities. • Best practice approval procedures, lessons learned are now commonly used, driven by central knowledge hubs across EU and shared with NA.	EU and NA ratify a Free Trade Agreement for electricity trade Real time pricing begins in the EU with the use of Smart metering Fossil fuel subsidies phased out in EU 1st phase funding in plan in place (public-private partnerships)
	North Africa • Further construction takes place to extend and upgrade NA grid capacity, including continuous upgrading of HVAC links. A review of energy access in remote areas in NA has been completed. Several HVDC cables connecting NA to EU are now in place. • The 1st set of centrally planned renewable energy generation plants is operational, with exports of electricity to EU underway. The 2nd programme of construction is on the point of receiving planning approval and starting construction.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	• Proposed demonstration and test sites are now operational. Lessons learned inform current construction, design and R&D. The need for further demonstration and test sites in NA is reviewed and agreed. • The first renewable energy component production plants / factories in NA are under construction. Capacity building programmes associated with the first wave of renewable energy construction have delivered a local workforce that is able to support larger programmes of work in future. Planning has been completed for the next round of renewable energy (solar, wind) production facilities to meet anticipated supply chain demands. • Engagement between in-country permitting and knowledge hubs institutions is now common place. • There is ongoing collection of solar radiation, wind data etc.	
2030 **Medium term milestone** No new construction of fossil fuel plants in EU Strategic decommissioning of FF plants in EU and NA begins EU wide SSG in place. Initial HVDC connections with NA begin Considerable electricity exports from NA to EU begin	**European Union** • Construction programmes over the past 20 years have reached the goals of the proposed Renewable Action Plan and ENTSO-E plan technology and generation infrastructure. The rolling plan is updated to reflect activities to 2040. • Offshore wind and other renewable energy now provide the largest share of total electricity generation across the EU. The build of replacement generation capacity commences to replace aging infrastructure by 2040. • A review is completed to understand progress and inform the plans to extend and upgrade EU grid capacity in the coming 10 years. The Grid Regulators and the mandate that they require to manage the new Super Grid are in place. • A significant number of renewable energy projects (wind, solar etc) are under construction in Member States. The EU plan is reviewed to address the need to replace aging generation infrastructure by 2040. • The regional EU Super Grid initiatives are converted into mini SuperSmart Grid networks (North Sea, Baltic Sea, and Mediterranean Sea). An EU Super Grid using HVDC links is in place. Regional Super Grids between EU and NA are connected. • The information obtained from the pilot and follow on projects to support the development of further programmes involving imports from NA and their interaction with the EU incentive schemes is reviewed and used to inform further projects. • There is now 10+ years understanding (supported by R&D) of how the EU grid system operation is able to cope with increased amounts of variable renewable power now connected to the grid. Action is taken to scale up the amount of storage technology that is in place to balance the increased renewable input. • Electromobility is established in several capital cities.	EU Directive on Grid Regulation implemented Strategy for decommissioning of EU FF plants implemented nationally 2nd phase funding plan in place

Milestone	Detailed enabling area activities	Cross-area dependencies
Large scale construction of REN generation capacity to meet 2030 national and regional targets and to replace decommissioned FF plants Substantial improvement in NA grid infrastructure	• Best practice approval procedures, lessons learned continue to be refined and improved based on experience. They are becoming standardised across EU and NA, driven by central knowledge hubs. **North Africa** • The NA grid infrastructure has been upgraded as planned and there is now near complete grid access available across NA. At least 10 HVDC cables connecting NA to EU are now in place. Plans for additional links are being finalised. • The 2nd set of centrally planned renewable energy generation plants is operational, with significant exports of electricity to EU underway. CSP with storage is in place as part of the new infrastructure to help balance the NA grid. The 3rd programme of construction is on the point of receiving planning approval and starting construction. • The proposed demonstration and test sites are now operational. They have completed their main objective to support large scale roll out of existing technologies. There is selective development of new sites to support emerging technologies only. • The focus turns to other infrastructure development opportunities. Studies to identify appropriate sites for desalination projects have been completed and initial tenders have been issued to support appointment of EPC contractors. There is consideration of electromobility schemes for NA locations. There is also activity underway to identify possible sub Saharan renewable energy links / projects including the initial development of the business case and identification of funding sources. • Engagement between in-country permitting and knowledge hubs institutions is now common place and beginning to expand its focus to include development projects. • There is ongoing collection of solar radiation, wind data etc.	

Milestone	Detailed enabling area activities	Cross-area dependencies
2040 **Long term milestone** The majority of EU FF plants are strategically or naturally decommissioned Extensive SSG grid infrastructure across EU and NA Large scale construction of REN generation capacity to meet 2040 regional targets and to replace decommissioned FF plants	**European Union** • Construction programmes over the past 30 years have reached the goals of the proposed Renewable Action Plan and ENTSO-E plan technology and generation infrastructure. The rolling plan is updated to reflect activities to 2050. • Offshore wind, CSP with storage and other renewable energy now provide the vast majority of total electricity generation across the EU. The build of replacement generation capacity continues to replace remaining aging infrastructure by 2050. The EU plan is reviewed to understand other activities needing to be completed by 2050 to replace all aging fossil fuel generation infrastructure. • A review is completed to understand progress and inform the plans to extend and upgrade EU grid capacity in the coming 10 years. The Grid Regulators begin to work more closely with their NA equivalents. • The number of renewable energy projects (wind, solar etc) under construction in Member States begins to decrease as installed capacity in NA increases. In combination these meet the agreed 2040 targets. • Mini EU SuperSmart Grid networks (North Sea, Baltic Sea and Mediterranean Sea) are in place. An EU Super Grid using HVDC links has been in operation for 10 years. Regional Super Grids between EU and NA are fully connected. • The information obtained from the pilot and follow on projects to support the development of further programmes involving imports from NA and their interaction with the EU incentive schemes is reviewed and used to inform further projects. EU incentive schemes are now finely attuned to NA electricity imports and are effective in encouraging ongoing construction of renewable energy in NA. • There is now 20+ years understanding (supported by R&D) of how the EU grid system operation is able to cope with increased amounts of variable renewable power now connected to the grid. Action is taken to further scale up the amount of storage technology that is in place to balance the increased renewable input. • Electromobility is established in almost all capital cities. • Best practice approval procedures, lessons learned continue to be refined and improved based on experience. They are becoming standardised across EU and NA, driven by central knowledge hubs.	Strategy for decommissioning of EU FF plants implemented nationally 3rd phase funding plan in place, largely for scale up of NA REN
	North Africa • The NA grid infrastructure has been upgraded and maintained as planned and there is now a SuperSmart Grid available across NA. More than 30 HVDC cables connecting NA to EU are now in place. Plans for additional links are being finalised.	

Milestone	Detailed enabling area activities	Cross-area dependencies
	• The 3rd set of centrally planned renewable energy generation plants is operational, with significant exports of electricity to EU underway. CSP with storage is in place as part of the new infrastructure to help balance the NA grid. The 4th programme of construction is on the point of receiving planning approval and starting construction. • The proposed demonstration and test sites are now operational. They have completed their main objective to support large scale roll out of existing technologies. There is selective development of new sites to support emerging technologies only. • There is selective decommissioning of certain existing NA fossil fuel generation plants and their replacement with renewable energy plants as these come on line. • The results of infrastructure development opportunities have been realised. Desalination plants have been built and are in operation across all NA countries using renewable energy. Electromobility has taken off in capital cities. There is consideration of electromobility schemes for NA locations. Initial sub Saharan renewable energy links / projects are in final planning and approval stages. • Engagement between in-country permitting and knowledge hubs institutions is now common place and beginning to expand its focus to include sub-Saharan locations. • There is ongoing collection of solar radiation, wind data etc.	
2050 **Long term milestone** **Final state** 100% REN power supply SSG in place across EU and NA Ongoing programme of REN generation construction	**European Union** • The connection of the mini SuperSmart Grids across the EU has resulted in an EU-NA wide SuperSmart Grid. • The power supply is reliable and based 100% on renewable energy sources. • Strong supply chains have been developed to support the industry allowing for infrastructure plans to consider the supply of 100% renewable electricity. • Long range planning of infrastructure projects is now well developed; rolling plans are developed for all generation and transmission requirements. • The decommissioning of fossil fuel plants is now complete. renewable energy generation capacity is the standard for all new build. **North Africa** • NA has a fully functionally SuperSmart Grid in place. There is significant installed capacity of renewable energy (all appropriate technologies) with electricity production meeting EU and domestic demands. More than 50 HVDC cables connecting NA to EU are now in place.	NA electricity export to EU balances national demand with export revenue Ongoing financing packages to support REN construction

Milestone	Detailed enabling area activities	Cross-area dependencies
	• The 4th programme of renewable energy generation plants is operational, and the 5th programme of construction is being planned. A long range plan is agreed to continue the development and construction of new renewable energy plants. • There is continued decommissioning of certain NA fossil fuel plants with replacement by renewable energy plants. NA is nearing a 100% renewable energy power supply. • Initial sub-Saharan renewable energy links / projects are now under construction. • There is ongoing collection of solar radiation, wind data etc.	

Appendix 3: Cost calculations and assumptions

Under current market conditions renewable electricity is generally not economically competitive with fossil fuelled power plants, or with existing nuclear power. Direct and indirect subsidies of fossil and nuclear power, as well as support schemes for renewable power exist in parallel, which makes a cost comparison difficult. Existing and depreciated large scale hydro power stations are the cheapest generation option. Modern wind power at very good sites can be competitive with coal power with the inclusion of the carbon price, but wind power is still on average more expensive than the conventional generation options (see below). Government incentives, such as feed-in tariffs, are currently the main drivers for investing in renewable electricity. However, the gap between renewables and conventional power is decreasing and is expected to continue to decrease, both due to technological development of the still immature renewable technologies and due to increasing prices for fossil fuels and carbon emissions.

The costs of generating power depend on many factors, of which some are project or investor specific. The fuel prices for fossil power plants are largely exogenously given, as are the largest parts of the investment costs for all generation technologies. All the economic parameters, such as discount rate, rate of return and other project specific factors, are hard to generalise to make a fair comparison for all technologies. The results are often very sensitive to changes in these economic assumptions. It is possible to manipulate the results in a desired direction by skewing the economic assumptions: if this is done skilfully, almost every result can be produced, even within a realistic set of parameters. Nonetheless, many studies do exactly these calculations and cost comparisons. Based on these studies, and with the appropriate uncertainty range, we make a comparison of generalised cost estimates based on the levelised electricity cost method (or in the case of HVDC transmission, levelised transmission costs). The results are presented below in Table 2 and Table 3.

The costs for coal, lignite and gas power are fairly well known as many such power stations have been built in the last year and many more are presently under construction. These cost data are therefore generally not disputed, but may vary strongly between projects. Disagreement regarding expectations of future fuel and CO_2 prices persists, and we therefore present a range of feasible investment, O&M and fuel costs. The costs presented in the table below are based on two meta studies[109-110], as well as the actual costs of a number of power stations under construction in Germany. The assumed carbon price is 15 €/t CO_2.

The costs of nuclear are harder to estimate and depend critically on assumptions in relation to discount rates, end of life costs etc. The IEA estimates that the investment costs for nuclear power plants are $1500-2500/kW (€1100-1800/kW)[109], others state costs of up to $7000/kW (€5150/kW)[111], whilst some anti-nuclear authors claim even higher costs[112]. The costs used for the comparison are the projected investment costs, obtained from the operators, for the only two European new-builds in Olkiluoto and Flamanville (€2100/kW) and actual costs as of late 2009 for Olkiluoto (€3300/kW).

As the CSP capacities are still very low, there are not many real power plants to base a cost estimate on. Most available data comes either directly from the German Aerospace Center (DLR) or the American National Renewable Energy Laboratory (NREL) or from a source that directly or indirectly cites one of these. We use this data too, as it is the best available[36, 113-115]. The model power plants considered are 50 MW with small storage (3 hours) for both parabolic trough and power tower. The site "Spain" refers to a site with a direct normal irradiance (DNI) of 2000 kWh/m^2/a, whereas the site "Sahara" is a site with 2600 kWh/m^2/a.

The wind power costs are based on an overview study of the costs of real wind farms, on- and offshore, in different countries around the world[116] as well as on other cost estimates for Europe[10, 79]. The offshore wind power costs are the projected costs and load factors of the 3 largest offshore wind farms installed in Europe in 2007 and 2008 (Burbo Bank and Robin Rigg, UK, and Lillgrunden, Sweden).

An interest rate of 10%, a discount rate of 10% and an amortisation time of 25 years were assumed for all technologies, except wind which was assumed to have a 20 years amortisation time. We assumed a carbon price of 15 €/t and emission factors of 0.9 kg/kWh, 1 kg/kWh and 0.5 kg/kWh for hard coal, lignite and gas, respectively[117]. The fuel-to-electric efficiencies of hard coal, lignite, gas and nuclear were assumed to be 50%, 50%, 60% and 40%, respectively[110].

Table 2: Costs and full load hours of new coal, lignite, gas, nuclear, CSP, PV and wind power plants. Costs are presented as the typical cost, with the minimum and maximum shown in brackets[39, 79-85, 89, 131, 133].

	Costs			
Technology	Investment (€/kW)	O&M (€/kW/a)	Fuel (€/MWh_{el})	LCOE (€c/kWh)
Coal	1200 (800-1600)	40 (26-97)	22 (18.4-30.8)	6.0 (4.8-8.3)
Lignite	1200 (1000-1400)	65 (26-97)	13 (10.8-14.8)	5.6 (4.5-6.6)
Gas	550 (400-700)	27 (11-42)	45 (34.8-57.2)	6.6 (5.1-8.2)
Nuclear	3000 (2100-3300)	55 (40-70)	4 (4-4)	5.9 (4.2-6.6)

	Investment (€/kW)	O&M (€/kW/a)	Full load hours (hrs)	LCOE (€c/kWh)
CSP (trough, Spain)	3300 (3000-3600)	70 (44-80)	2500 (2500-2500)	17.3 (15.0-19.1)
CSP (trough, Sahara)	2500 (2300-2700)	70 (44-80)	2500 (2500-2500)	13.7 (11.7-15.1)
CSP (tower, Spain)	3500 (3000-3900)	100 (90-115)	2500 (2500-2500)	19.4 (16.8-21.8)
CSP (tower, Sahara)	2600 (2300-2900)	100 (90-115)	2500 (2500-2500)	15.6 13.5-17.5)
PV	3700 (2500-5100)	22 (15-26)	1500 (1300-1500)	28.4 (22.3-39.2)
Wind (onshore)	1200 (1000-1300)	23 (13-30)	2300 (2000-2400)	7.1 (6.5-8.6)
Wind (offshore)	2200 (1600-2700)	50 (36-58)	2800 (2500-3300)	11.0 (9.0-11.4)

The literature regarding the costs of transmission is not very broad, and there is circular referencing between sources. For the considerations here we have used the projected costs for a number of cables across the Mediterranean[29], data from the Baltic cable and a number of other sources, citing both real projects and estimates of current HVDC line costs and losses[5, 11, 76-77]. For the calculations of the levelised transmission costs (LTC), a value of the input electricity of 5-15 €c/kWh (to represent current feed-in of onshore wind and CSP), an amortisation time of 25 years and a discount rate of 10% were assumed.

Table 3: Costs for HVDC transmission, assuming a 2000 km HVDC line and 200 km subsea cable. Costs are presented as the typical cost, with the minimum and maximum shown in brackets[5, 11, 76-77].

	Costs					
Technology	Value of input electricity (€c/kWh)	Investment (line) (€/kWkm)	Investment (subsea) (€/kWkm)	Converter (€/kW)	Full load losses (%/1000 km)	LTC €c/kWh
HVDC	10 (5-15)	0.1 (0.07-0.3)	1.3 (1.1-1.4)	60 (60-70)	2% (2-3)	1.8 (1.2-3.7)

Appendix 4: Case studies

Lessons learned from other large programmes of work

This report has highlighted that the vision proposed for Europe and North Africa will require coordinated political and industrial will over a number of years. In addition, a myriad of technical and other challenges and barriers will need to be identified and addressed on a timely basis. Opponents to this vision may see these challenges, such as development in areas with high geo-political risk or financing multi-billion pound infrastructure projects in new technologies, as insurmountable.

This section provides details of a number of programmes of work where similar barriers to those that can be expected with the implementation of the vision proposed in this report have been experienced and successfully overcome. A brief introduction to the project, the barriers that have been encountered and the key learnings that can be taken from the work are outlined below.

The following case studies have been considered:

Case study	Barrier	Programme / Project	Location
1	Technology risk	Solar Energy Generating Systems (SEGS)	California, USA
2	Geopolitical risk	African gas pipelines	Algeria, Morocco, Tunisia, Libya, Spain, Italy
3	Long distance and trans-boundary HVDC lines	Baltic cable	Sweden, Germany
4	Financial incentives	Feed in tariff	Germany, Spain
5	Bilateral power exchange agreements	Fingrid electricity imports	Finland, Russia
6	Europeanisation of a intrinsically national system	Introduction of the Euro	Europe

Case study 1: Technology risk

Background

The US energy crisis and the oil embargo in the 1970's forced the need to more seriously consider alternative energy sources onto the agenda of politicians and energy engineers. One of these was CSP and, although it was not a new concept, CSP had not yet been proven before on a commercial scale anywhere in the world. To encourage its development, the state and federal governments agreed to provide investment tax credit for solar developers to plan and build large scale projects. Californian based Luz International Ltd. (Luz) took advantage of the investment tax credit to develop the first parabolic trough plant, Solar Energy Generating Systems (SEGS), in 1984 in the Mojave Desert.

Between 1984 and 1990 Luz built and sold a total of nine parabolic trough solar power plants. Driven by the availability of the financial support scheme in the early years, the construction of these plants was in later years also supported by special power purchase contracts that were available in California. To reduce the initial technology risk and increase their reliability and dispatchability, the design of the plants was such that the solar fields were hybridised with gas turbines (although the fossil element contributed less than 25% of the output). Each of the plants was developed as an independent power producer project, financed with non-recourse debt, and sold to investor groups. In total, over $1.2bn was raised during the 1980's to finance these projects[118]

Each new plant provided an opportunity to develop and progress the technology, putting into practice lessons learnt from the previous installation and taking advantage of technology advances. SEGS is currently still the largest solar energy generating facility in the world with an installed capacity of 354 MW. Generating costs have been significantly reduced throughout the build of the SEGS plants, from a reported 24 US¢/kWh at SEGS I to a reported 3-6 US¢/kWh at SEGS IX[118] (although these costs are not well documented in literature and therefore remain uncertain). This very low operational cost for SEGS IX is possible due to the full repayment of all capital loans.

The SEGS installations demonstrated that solar installations typically incur 80% of whole life project costs as upfront capex and therefore require very large loans. Traditional power plants on the other hand, require only 20% of costs as capex. However fuel costs over the life time of the project are far more significant but these can be purchased as a continuous string of payments during the lifetime of the plant.

Solar installations are also associated with greater perceived and real technology risks when compared with traditional power plants. This will result in considerably higher interest rates and financing costs for loans for CSP plants. In addition, capital investment in a solar field is often taxed differently than expenditure for fossil fuels[118]. The financing mechanism and the loan terms will therefore have a disproportionate impact on the LCOE economics and when the loans are repaid, small overhead costs and no fuel costs result in a very low generation cost of electricity.

Luz declared bankruptcy in 1991 whilst in the process of building its tenth plant. A number of factors are thought to have contributed to this, but it was reported that the primary cause was a decrease in energy prices coinciding with the phasing out of state and federal investment tax credits, delays in the extension of the California solar property tax exemption and the inability to obtain construction financing. Technology problems were not thought to be a factor – indeed SEGS I-IX were sold to operating companies prior to 1991 and are still generating carbon free electricity today. From an operational perspective they have been very successful and continue to provide useful operational data to support other solar projects around the world today.

Note: It is interesting to see that as this report is being written the US government, under President Obama, is again beginning to channel large amounts of investment to support the renewables sector, and in particular solar. The net effect has been a resurgence in the development of large scale solar projects in the South West US supported by multi billion US$ loans from the US Department of Energy all of which are looking to build on the experience of the original SEGS plants.

Key learnings

- Solar technology works. In additional to producing electricity on a commercial scale, the SEGS plants have also demonstrated that if well maintained, the operational life is 25+ years.
- Increases in installed capacity along with ongoing technology enhancements will result in lower LCOEs and useful operational information that can be used to guide future R&D activities.
- Pioneering companies who take on technological risk should be supported by government. It is important that the focus is on long term benefits rather than short term gains.

SEGS plant, California

Case study 2: Geopolitical risk

Background

A number of African countries have rich oil and gas reserves. Pipelines are therefore commonly used to transport fuel from the oil and gas fields to refineries, centres of demand or to the coast for export. Many of these are pipelines are within national borders, such as the 15 oil, gas and refined product pipelines within Nigeria[119].

Other gas pipelines are cross border, transporting gas from North African facilities to the European market, often over very large distances. Examples of some significant pipeline infrastructure projects include:

- Trans-Mediterranean (1983);
- Maghreb-European Pipeline (1996);
- Greenstream (2004); and
- Medgaz (2010).

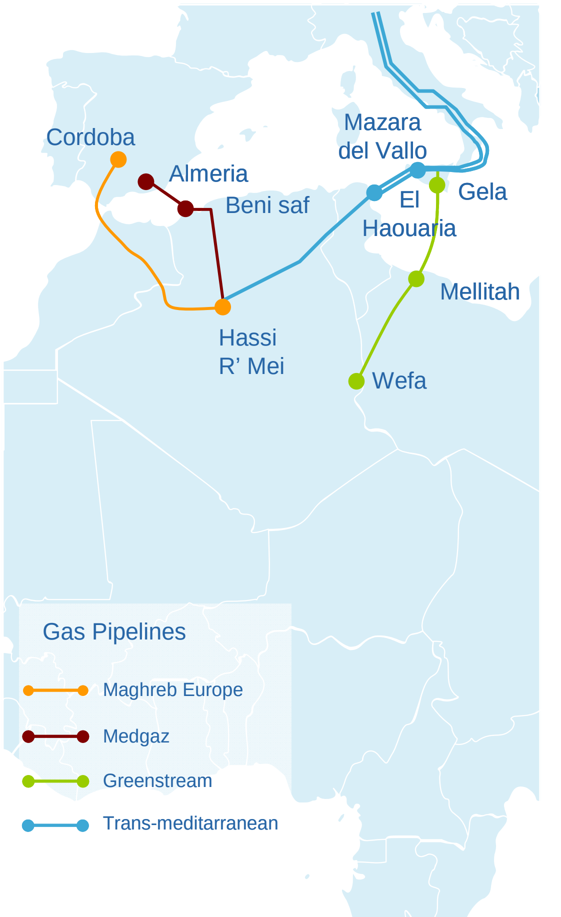

Figure 12: Gas pipelines connecting North Africa and Europe

The cross border pipeline projects have involved Algeria, Morocco, Tunisia, Libya, Italy and Spain. What they have in common is that they are typically undertaken by a consortium of both European and African companies. The pipeline ownership is often divided by geographical boundaries and with companies from the respective country owning and/or operating the specific pipeline section.

The ownership of the Maghreb-European Pipeline, for example, is split into county sections: the Algerian section is owned and operated by Sonatrach (Algerian), the Moroccan section is owned by the Moroccan State and operated by Metragaz (a joint venture of between Moroccan, Spanish, Portuguese companies) and the offshore section crossing the Strait of Gibraltar is owned jointly by Enagás (Spanish), Transgas (Portuguese), and the Moroccan state[120]. In a similar way, the Greenstream pipeline was constructed and owned by Agip Gas BV, a joint venture of the Eni (Italian) and the National Oil Corporation (Libyan)[121].

As with many large construction schemes, there are/were opponents to these pipelines and fears that political instability within and between operating countries would threaten the projects. These have been overcome with the use of a number of mechanisms and appropriate legal tools to bind countries and companies. Intergovernmental agreements and Memorandum of Understandings and power exchange agreements are examples of such. Contractual arrangements such as long term take-or-pay contracts which obligate the buyer to pay a minimum amount for the product, even if it is not delivered, are also important.

It is worth noting that very different countries have successfully worked together to progress the plans and construct these pipelines. With the pipelines in place, there is also no evidence that gas supplies from North Africa have been less secure a source for Europe than those that are produced domestically[122]. Finally, there would not appear to be any reasons why the same mechanisms described above for the construction of gas pipelines could not be used for HVDC transmission line development as the infrastructure requirements have many elements in common.

Long distance transmission lines are less common in Africa, with the exception of the world's longest HVDC link, the Inga-Shaba 1,700 km link connecting the Inga Dam to the Shaba copper mine in the Democratic Republic of Congo. Despite financial overspend and initial under-utilisation of the link, this link has been successfully operating since 1982.

Key learnings

- Countries with very different political systems and interests can work together on the achievement of a common infrastructure goal.
- It is possible to finance large scale infrastructure projects in Africa. Once built, infrastructure can be maintained to the standards required.
- The perception that projects may be subject to increased geopolitical risk in some African countries has not been evident with the gas pipelines. It is worth noting that North African countries have historically been more stable politically than many Central African countries which already have operational pipelines and transmission lines in place.
- Gas pipelines that connect North Africa with Europe already exist. They operate on a commercial basis, are functional and are no less secure than domestic assets.
- The construction of electricity transmission lines can build on the experience and approach used to develop the gas pipeline network. Some specific mechanisms common in gas pipeline projects, such as 20 year take or pay contracts, may not be suitable for the electricity market due to the substantial time periods, but joint asset ownership, legally binding power exchange agreements and MoU's can certainly be translated to long distance transmission lines.

Case study 3: Long distance and trans-boundary HVDC lines

Background

Long distance and trans-boundary HVDC lines utilise a proven technology and are currently used in numerous locations worldwide. They are favoured over HVAC due to lower transmission losses over large distances, in particular when submarine cables are required.

The first DC lines were built in the 1880s and were typically no more than 100kV or 50 km in length. The 1960s-1980s saw a significant growth in the use of HVDC lines in addition to considerable improvement in the technology. Typical lines were 500kV with lengths up to 1000km. Today's HVDC projects are operating or are planned to operate at 800kV over distances exceeding 2000km[123].

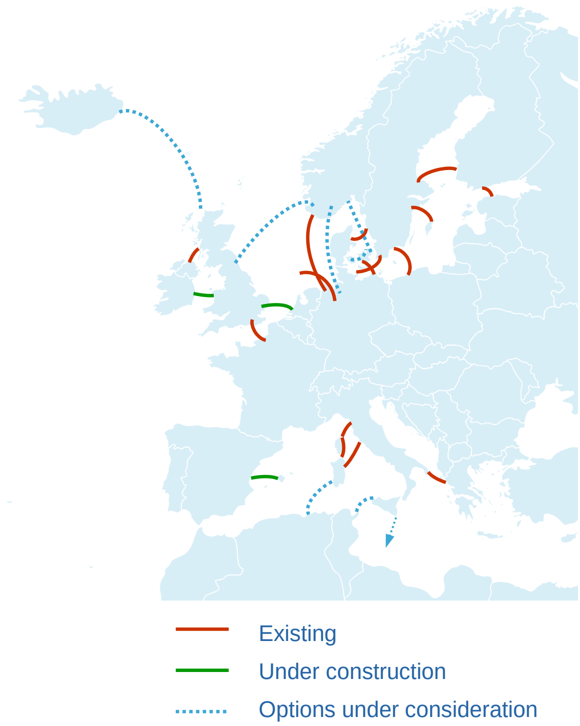

Figure 13: Trans-boundary HVDC interconnections in west Europe

In developed countries, cross boundary links and interconnections between asynchronous areas are the most common. The purpose of these are either to:

- Supply power to countries which do not have the domestic capacity to fulfil their demand, such as the Russia-Finland connection;
- Increase energy security by diversifying the resource use and location of electricity generation; or
- Optimise energy resources by connecting countries with different consumption patterns.

In Europe, all links are currently submarine (see Figure 13), the only exception being the B2B connections to the Russian system. One notable example is the Baltic Cable, a Sweden-Germany connection that includes 250km of submarine cable across the Baltic Sea. This cable was completed in 1994 at a cost of US$280 million. It has since allowed capacities to be managed in such a way that they complement each other optimally. The manufacture of this cable took place using two parallel production lines operating 24 hours per day, 7 days per week for 1.5 years. It was then laid by a cable laying vessel in two lengths using a sea joint.

In developing countries, links are often long distance with the purpose of connecting isolated sources of electricity generation with centres of consumption. One example is the Xianjiaba – Shanghai connection in China, which will exceed 2000 km in length and operate at 800kV when it is completed in 2010[124]. The line will transmit 6,400 MW power from the Xiangjiaba hydro power plant, located in the southwest of China, to Shanghai, China's leading industrial and commercial centre.

This line will in time be surpassed in length by the Rio Madeira link in Brazil. When completed in 2012, this will connect two hydropower stations in Porto Velho in northwest Brazil to Sao Paulo in the south east, a distance of some 2500km[125].

Key learnings

- Long distance HVDC lines are a proven technology. There are numerous commercial examples already in operation under a variety of conditions around the world.
- The technology continues to evolve providing greater transmission opportunities. Recent trends in the application of HVDC lines demonstrate the use of increasing voltages, power ratings and length.
- The majority of links in developed countries are across international borders. Cross boundary links will incur additional permitting requirements but bi-country cooperation in this area is common.
- In developing countries, HVDC links are increasingly used to transmit electrical energy extremely long distances, from isolated areas of generation to centres of consumption. Important operational experience therefore exists to support this in EU-NA.

Case study 4: Financial incentives

Background

There are a great number of market-based instruments that governments use to subsidise renewable electricity. These can be classified as either investment support (capital grants, tax exemptions or reductions on the purchase of goods) or operating support (feed-in tariffs, price subsidies, green certificates, tender schemes and tax exemptions or reductions on the production of electricity). Investors determine their terms of investment, such as their require rate of return, in part on the basis of the risk associated with the project. Therefore well designed subsides will act to lower the financial risk, which in turn leads to more favourable finance and lower operating costs. As operating costs reduce, the cost of the subsidy to the Government can be scaled down accordingly. The need to design an effective and efficient subsidy scheme is therefore of utmost importance to the costs incurred by both the Government and developers.

Notable examples include the German and Spanish feed-in tariff and the US investment tax credit which have all facilitated significant growth rates in solar and wind generation. It is generally considered that well-adapted feed in tariffs are the most efficient and effective mechanism of financial support[126] by providing long term guaranteed price per kWh produced and targets a 5-10% return. However it should be recognised that different instruments can be used to address different market issues, such as the use of the investment tax credit to reduce the barrier of high capex costs of renewable installations

It is therefore vitally important to tailor the design of policy instrument to the specific market and the corresponding market barriers. Different policy designs, even to the same financial mechanism, can create significant different markets as illustrated by the boom and bust trends seen in the Spanish and US solar markets, in comparison to the stable and continuous growth of the German solar market. At a high level, the success of Germany's feed in tariff is attributable to a number of key features[127]:

- The tariff rates for different renewable technologies are based on the cost of power generation from each resource and from different sizes of projects; there is no flat rate across all renewables;
- Long term purchase guarantees provide security for the next 20 years; and
- The tariff rates decrease annually to encourage technical innovation and cost reductions. The degression rates vary from 1% to 6.5% depending on the technology[128].

Levels of incentives

The German system sets a very favourable rate of € 0.319 /kWh for ground installed solar energy systems. In Spain this is €0.27 /kWh. Despite this being substantially lower, it is still considered to be appropriate to cover the costs and the risks associated with constructing some of the first CSP plants post-SEGS in the US, mainly due to the increased solar irradiance in Spain.

For other forms of renewables, the levels of incentives vary by installation size and by country, for example:

- **Wind:** from 0.057 €/kWh (Switzerland) to 0.129 €/kWh (Ireland)
- **Biomass:** from 0.045 €/kWh (France) to 0.160 €/kWh (Croatia)
- **Hydro:** from 0.038 €/kWh (Hungry and Austria) to 0.168 €/kWh (Switzerland)
- **Geothermal:** 0.054 €/kWh (Estonia) to 0.193 €/kWh (Switzerland)

Incentive caps

However the key difference between the German and Spanish systems is in the use of caps and other mechanisms.

In Spain to encourage investment there was also an added premium for the first 200MW of installed CSP capacity. This, not surprisingly, resulted in rapid growth in the solar capacity under development with the result that the Spanish Government then had to introduce a cap on the financial support, limiting it to the first 500MW of installed capacity. A sharp decline in the growth rate of new solar installations followed. The other cap that was imposed restricted the financial support available for the government to installations up to 50MW in size. Whilst this was intended to promote thermal storage which would otherwise be uneconomical, it also had the effect of reducing the likelihood of the industry to reduce costs through economies of scale.

Despite this, the Spanish system has other features which are favourable, such as the allowance for natural gas back-up to improve the reliability of the plants and a longer guaranteed tariff rate (25 years).

The importance of stability

Long term stability and certainty in the support schemes are crucial to reducing the risk to investors and maintaining steady growth in the market. A comparison of the support schemes for wind power in Germany and Sweden illustrates this, as shown in the figures below: Sweden has introduced a large number of different schemes with 4-5 operational at any one time, the value of which is small and has varied by almost 100% in recent years. The German system however, has been based on a maximum of 2 schemes at any one time, the value of which has remained constantly high since 1996. As a result, installed wind capacity in Sweden remained under 0.5GW in 2004, whilst Germany boasted 16.5GW and impressive growth rates.

Key learnings

- Policy mechanisms have the potential to transform the market. Key features must include longevity, transparency and stability.
- There is substantial experience from existing policy schemes which have been implemented with varying levels of efficiency and effectiveness. Governments must learn from these when design and implementing new mechanisms.
- Reducing the risk for investors decreases the cost of the support scheme and increases both efficiency and effectiveness. The government needs to understand the likely costs of any policy mechanisms over the long term so as to minimise the likelihood of stop:start periods for the renewables industries.
- Policy instruments must be very well designed and adapted to the technology and the market for which they are intended. They also need to consider the likely technology advances in years to come.

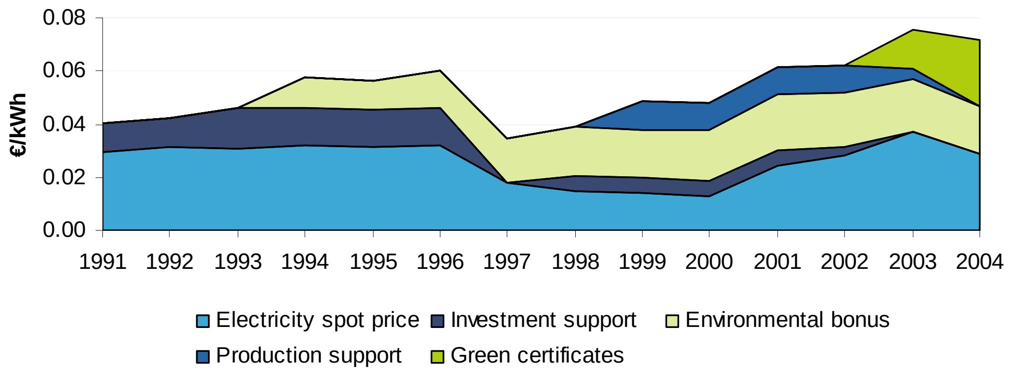

Figure 14: Support schemes for wind power in Sweden

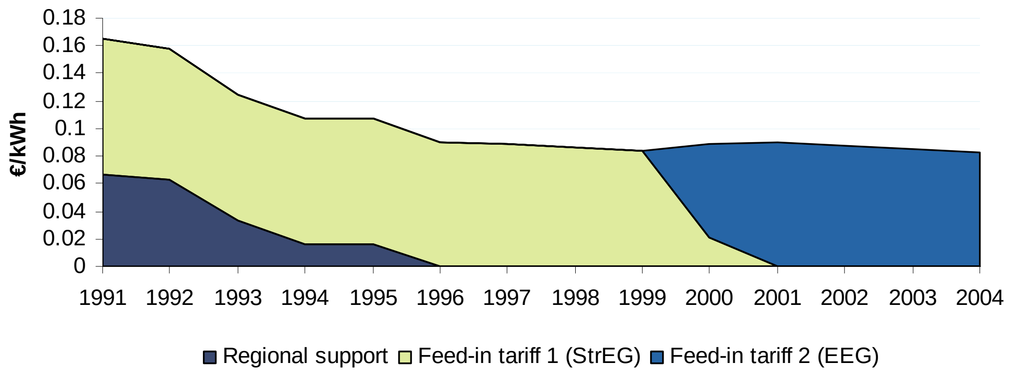

Figure 15: Support schemes for wind power in Germany

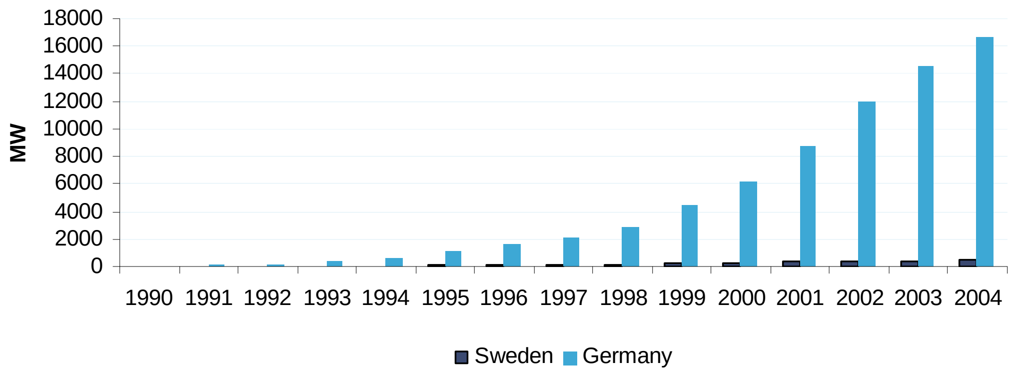

Figure 16: Installed wind power capacity in Sweden and Germany

Case study 5: Bilateral power agreements

Background

Many European countries strive to be self sufficient in terms of electricity supply and they view the concept of importing electricity with a fear of increased dependency on other countries and a decreased security of supply. However, almost all European countries are heavily dependant on imports of coal, gas, oil and uranium which are ultimately used for their electricity supply. In 2006, the EU imported over 50% of its energy from outside of the EU[3, 38] therefore the EU's dependency on other countries is already substantial. It is important to note, however, that because electricity cannot be stored, countries are more sensitive to a disturbance in the electricity supply in comparison to the fuel supply. Stockpiles of electricity cannot be accumulated. In addition, coal and oil is "delivered" to a country at a large number of locations by an even larger number of tankers or trains, whilst electricity is typically imported at a small number of specific locations i.e. at cross-border transmission lines. Again, the reliance on fewer import channels renders electricity imports more sensitive to disruptions. However gas imports also rely on a limited number of linear infrastructure at specific locations, and despite this gas imports to Europe increased by 29% between 2000 and 2006[27].

Electricity trading has been occurring between a number of European countries and their neighbours for over 25 years, albeit at small scales and few depend on such. The trade is for two main reasons: to take advantage of the price differential between countries and as a contingency measure in times of shortfalls in domestic electricity supply. Finland, Italy and the Netherlands which all import between 15-20% of their electricity demand[129,130-131].

The Netherlands imports more than 20% of its electricity from Germany and Belgium, France and the UK[131]. This was built up in a period when neighbouring countries had surpluses, which is now no longer the case and therefore has the potential to impact upon secure and cost-competitive deliveries in times of shortages.

Finland imports 15% of its domestic electricity requirement (13 TWh), primarily from Russia but also from Estonia.

Despite political and economic changes in Russia, this trade has been very stable over 25 years and there have been virtually no supply disruptions. A number of contractual agreements are used between the players in Finland and Russia to ensure this, such as a 20 year power purchase agreement and import contracts, as well as practical arrangements including transmission service agreements and system agreements. The arrangements used for securing electricity imports can be summarised as:

- Fingrid offers capacity on its transmission connections from Russia to Finland in lots of 50MW;
- The Russian grid operator agrees with the Russian electricity seller on the electricity supply;
- The Russian grid operator notifies Fingrid on the transmission reservations;
- Fingrid makes the corresponding transmission service agreement. This agrees that the Russian customer reserves a transmission right for a time period and is intended for a fixed-type import of electricity; and
- Fingrid is responsible for the daily management of the power balance between Finland and Russia.

The arrangement described above facilitates a proven and successful bilateral power exchange agreement and provides us with a model upon which initial power trade between Europe and North Africa could be based.

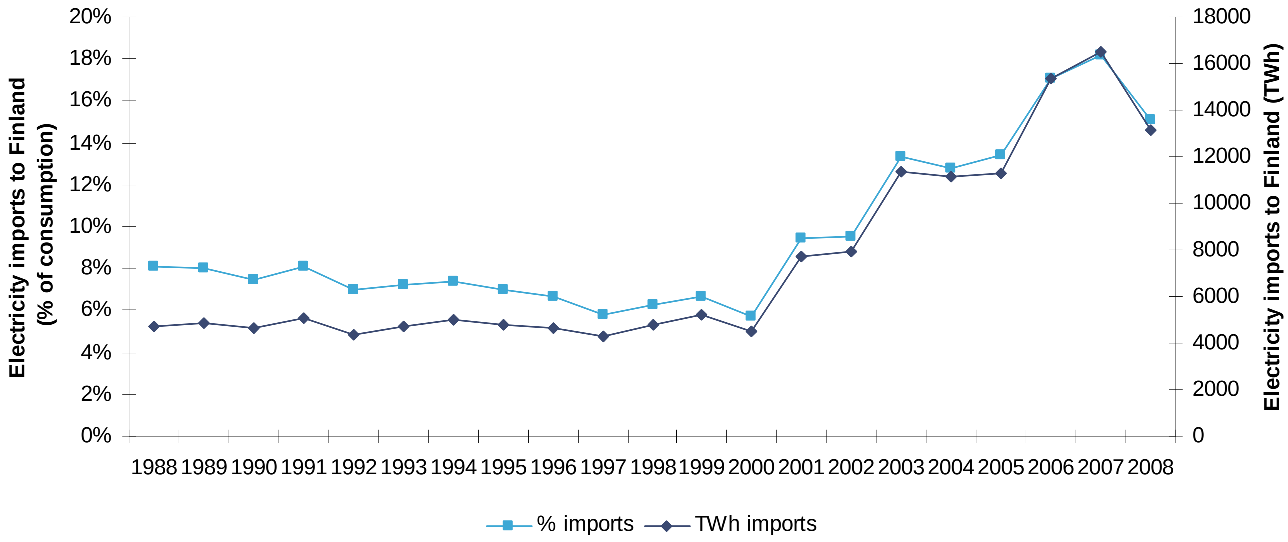

Figure 17: Finland electricity imports from Russia[132]

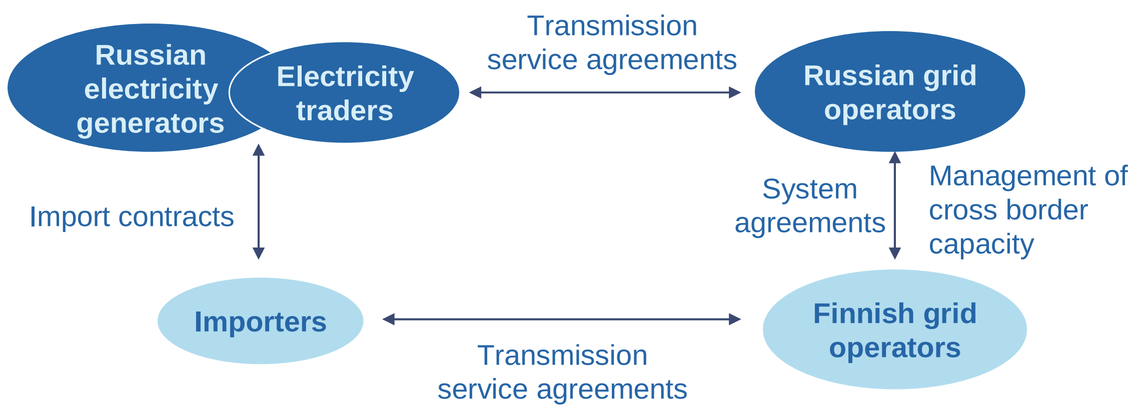

Figure 18: The structure of electricity imports from between Finland and Russia[133]

Key learnings

- Importing electricity can be related to importing the fuel for electricity which the EU currently does at levels in excess of 50% of its energy needs. However, countries will be more sensitive to disturbances in electricity supply rather than fuel supply because electricity cannot be stored or stockpiles formed.
- Importing and exporting electricity is a commonly used method of overcoming shortfalls in domestic energy supply, especially in the UCTE, although it rarely comprises the majority of a countries energy demand.
- Existing power trade agreements between long term power importers such as Finland provide a model for the initial import of electricity from North Africa. The structure and use of contractual agreements to ensure a secure supply will differ between countries, between intra-and inter-European trade and due to variation in the level of integration and market concentration. These may include: bilateral power agreements, transmission service agreements, system agreements and import contracts.

Case study 6: Europeanisation of an intrinsically national system

Introduction of the Euro

Background

The Euro is the single currency shared by (currently) 16 of the European Union's Member States, which together comprise the Eurozone. It was established by provisions in the 1992 Maastricht Treaty, introduced in 11 countries as a virtual currency for cashless payments in 1999, and subsequently as a hard currency in 2002. It has since been adopted by 5 further countries and has become the second global currency, after the US Dollar.

A country's monetary policy and currency are vital to its economy and prosperity and therefore the Europeanisation of such is a very sensitive national issue. Energy policy and security are similar in nature and if it is politically and logistically possible to create a common European currency it is far from impossible to unify energy policies and create a centrally optimised power supply, although the time scales for achieving this may vary.

Policy

The policy instrument for the introduction of the Euro was the Maastricht Treaty (Treaty on European Union, 1992). This set the foundation for the Euro through the establishment of the Economic and Monetary Union (EMU). The aims were to achieve economic integration, a single market and therefore a single currency through the co-ordination of economic and fiscal policies. The Treaty set out the ground rules for its introduction, outlined the objectives of the EMU and determines who is responsible for what, and what conditions Member States need to meet in order to adopt the Euro.

Governance

Striking the balance between centrally and nationally controlled policies and regulation, and therefore the level of autonomy retained by each Member State, was critical to the Euro's uptake and success. The division of these between institutions is outlined below[134]:

- The European Council: sets the main policy orientations;
- The Council of the EU: coordinates EU economic policy-making and decides whether a Member State may adopt the Euro;
- The "Eurogroup": coordinates policies of common interest for the Euro-area Member States;
- The Member States: set their own fiscal policy including tax, spending and structural polices involving labour, pensions and capital markets. There is a requirement to adhere to commonly agreed rules on public finances (the Stability and Growth Pact);
- The European Commission: monitors performance and compliance;
- The European Central Bank: sets monetary policy, with price stability as the primary objective; and
- It is important to realise that the Euro does not bring economic stability and growth on its own. This is achieved through the sound management of the Eurozone economy under the rules of the Treaty and the Stability and Growth Pact, a central element of the EMU.

Surviving crises – the national optimisation of central decisions

The 2009 recession and the fiscal crisis in Greece in January 2010 is putting the Euro under its biggest strain in its history and has raised some very important questions which should be taken into consideration in future Europeanisation programmes. The key concern is how best to ensure fiscal discipline within a monetary union. The Stability and Growth Pact has not been successful in achieving this so far.

Key learnings

- The introduction of the Euro provides valuable lessons that can support the transition to a European-optimised renewables based power market. If it is possible to create a common European currency - which is an issue at the very core of a state - it is reasonable to believe that it is also possible to unify the energy policies. The time scale for achieving these outcomes however, will vary.
- It is possible to align very different Member States along a common outcome, in this case the adoption of a single currency over a period of time. Delivering on policy agreements and the confidence that other countries will do the same is vital.
- Although the transition was challenging, careful planning, appropriate governance structures and an EU-wide approach to dealing with challenges have meant that the introduction of the Euro is generally seen as a logistical success. However, it should be acknowledged that the continued operation of the Euro is economically and politically demanding and costs and benefits are not always shared equally by participating countries.
- Entry requirements can be used to ensure a level of standardisation across all Member States and build in a minimum threshold in terms of preparedness and quality of existing systems. But there is then a challenge in maintaining these entry standards over time.
- It is important to retain national autonomy where European governance is not essential to ensure that countries retain the appropriate level of national control. Where this occurs, national policy should be guided by centrally agreed rules. Fiscal policy is an area where this does not seem to have worked well in EMU to date.
- When designing governance frameworks, consideration should be given to the full range of likely future scenarios. This will help with the development of decision making processes that are used to review and respond to possible future problems and issues as they arise.

Appendix 5: Taking the roadmap forward – additional study areas

This report has outlined a roadmap to achieve a vision of a decarbonised energy sector in EU-NA by 2050. There are a number of adjacent areas and topics that have not been addressed in detail. Examples of areas that warrant further consideration as part of taking this roadmap forward include:

1 Finance and investment

- **Finance and costs**: There is a need to understand in more detail the cost of arriving at the 2050 vision proposed in this report. For infrastructure projects, this could be done in the form of a business case that captures this information in such a way that it facilitates the structuring and financing of the underlying schemes. It will also be necessary to understand the impact on the end consumer over time of the planned investment in renewable infrastructure.

- **Business model:** With electricity exports becoming more common, there will also be a need to develop new models that support the costing and management of projects associated with exports.

2 Policy work programmes

- **Programmes of work:** There is a need to map the relationship and interdependencies between the policy roadmap proposed, other existing programmes and work programmes that may emerge in future.

- **Delivery:** A number of energy policy mechanisms already exist to support the delivery of the roadmap proposed. A review of these to identify gaps, the success of each to date and the role they should play in future is needed, first at a national and then a regional level.

- **2050 transition planning for when vision is achieved:** The realisation of the 2050 vision will not halt the need for momentum in the European and North African power sectors. Many of the initial renewable deployment plants will then be nearing the end of their natural lives and will require replacement, technology will still be advancing and the geographical focus of the SuperSmart Grid may be extended to join with other regional initiatives that have developed e.g. the Middle East and sub Saharan Africa.

- **Decommissioning strategy:** Due to an aging asset portfolio in Europe, many fossil fuel power plants will be decommissioned over the next 20 years at the end of their useful lives. In addition to this, some may be strategically decommissioned before their end of life in order to meet climate targets. These activities should be coordinated temporally and spatially with the planning of new generation capacity, whilst also recognising that the enforced closure of fossil fuel plants will be a highly political activity.

- **Other policy areas:** Energy policy should be closely linked with other policies developed by EU-NA governments at a regional or individual country level. Examples of other policy areas where activities should be coordinated include environment, transport, and housing. Linkages will need to be mapped in more detail between these areas to ensure that existing and new policies continue in energy and other policy areas continue to support and reinforce the 2050 vision.

3 Technology

- **Technology assessments:** A variety of renewable energy technologies exist today that could meet many of the requirements outlined in the vision for 2050. This report has not looked to “score” or compare different types of renewable technology. An initial assessment should be completed and further reviews will then be required, especially as lessons are learned and developments take place to advance existing or introduce new technology.

- **Energy efficiency:** If successfully implemented on a large scale, energy efficiency has the potential to significantly decrease our emissions through lower demand. This will need to be taken into account in developing the plans and policies to support the investment in generation and transmission infrastructure.

- **Heat:** Energy is also currently being used to provide heating (and cooling) for residential and business use. It will be necessary to consider how renewable electricity could support this requirement, particularly as government policy begins to have an impact on levels of demand and on the use of fossil fuel alternatives.

- **Desalination:** Using CSP plants to power seawater desalination, either by electricity or in combined generation with process steam, presents the opportunity to supply both power and freshwater to a growing population in North Africa. A small number of desalination CSP plants are being planned but it is acknowledged that there is a need for a greater understanding of the trade-off between energy generation efficiency and desalination.

- **Electromobility:** If coupled with a transition to an electrified transport system, a 100% renewable power sector could provide enormous potential to reduce global GHG emissions. Similar to the roadmap presented here, electrifying the transport system will require significant policy support, substantial investment in R&D, a programme of new infrastructure planning and, importantly, the creation of consumer demand. The planning and development of the future power system should give full consideration of the growth of electromobility.

4 Geography

- **Middle East:** The geographical scope of this report has only considered the EU and North Africa. The Middle East also offers tremendous renewable energy opportunities, especially in the area of solar energy. Work could be undertaken to advance the existing Desertec and DII studies and the vision proposed by this report to examine, at a policy level, what needs to be done to include some or all of the Middle Eastern countries.

- **Africa:** The report has also only considered some of the North African countries bordering the Mediterranean Sea. Renewable technologies, especially solar, also hold great promise for the rest of Africa. It would make sense, once progress has been made in North Africa, to investigate further how the necessary policy and infrastructure could be developed to (i) link sub Saharan countries to developments in North Africa, as well as (ii) promote similar projects within and across sub Saharan countries.

- **Asia Pacific and South America:** These regions also have great potential to harness renewable energy as part of an integrated approach. Further work should be carried out to consider what a possible roadmap for these regions could look like.

5 Delivery

- **Capacity and capability:** Many countries will not have the necessary organisational and people capacity / capability in place to support the development and delivery of a programme of this complexity. It will take time to recruit, train and establish the individuals needed to support the in-country organisations and processes. Close coordination between countries would help to smooth and speed up this process, both in the terms of lessons learned, regional coordination and in the sharing of implementation delivery activities.

Appendix 6: References

1. Umbach F. Global energy security and the implications for the EU. *Energy Policy.* 2010; 38:1229-1240.
2. MacKay DJ. *Sustainable energy - without the hot air*. Cambridge, UK 2009.
3. Eurostat. Energy and Transport in Figures. Statistical Pocketbook 2009: European Commission; 2009.
4. International Energy Agency (IEA). Statistics by country and region. 2009; http://iea.org/Textbase/stats/index.asp. Accessed 13 July 2009.
5. German Aerospace Center (DLR). *Trans-Mediterranean Interconnection for Concentrating Solar Power,* 2006.
6. Directorate-General Transport and Energy (DG TREN). European Energy and Transport. Trends to 2030 (2007 update): European Commission; 2008.
7. International Energy Agency (IEA). World Energy Outlook 2009, 2009.
8. Teske S, Beranec J, Tunmore S, et al. Energy [R]evolution. A Sustainable Global Energy Outlook: Greenpeace, European Renewable Energy Council (EREC); 2008.
9. Cox B, Cooke A, Fox T, et al. UK 2050 Energy Plan. Making our Committment a Reality: Institution of Mechanical Engineers; 2009.
10. Nitsch J. Leitstudie 2008. Weiterentwicklung der "Ausbaustrategie Erneuerbare Energien" vor dem Hintergrund der aktuellen Klimaschutzziele Deutschlands und Europas. Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU); 2008.
11. Czisch G. Szenarien zur zukünftigen Stromversorgung. Kostenoptimierte Variationen zur Versorgung Europas und seiner Nachbarn mit Strom aus erneuerbaren Energien. Kassel: Institut für elektrische Energietechnik / Rationelle Energiewandlung, Universität Kassel; 2005.
12. Union for the Co-ordination of transmission of Electricity (UCTE). *Statistical Yearbook 2007,* 2008.
13. Nordel. *Annual Statistics 2008,* 2009.
14. Union for the Co-ordination of Transmission of Electricity (UCTE). *Annual Report 2008,* 2009.
15. European Network of Transmission System Operators for Electricity (ENTSO-E). 2009; http://www.entsoe.eu. Accessed 24 November 2009
16. Deutsche Energieagentur (DENA). Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020, 2005.
17. Battaglini A, Lilliestam J, Haas A, Patt A. Development of SuperSmart Grids for a more efficient utilisation of electricity from renewable sources. *Journal of Cleaner Production.* 2009; 17 911-918.
18. European Transmission System Operators (ETSO). European wind integration study. Towards a successful integration of wind power into European electricity grids, 2007.
19. Grohnheit PE, Møller Andersen F. Is more than 25% wind power feasible in a regional electricity market. Vienna: IAEE European Conference "Energy, policies and technologies for sustainable economies", 7-10 September 2009.
20. Viehmann J, Sämisch H. Windenergieintegration bei negativen Strompreisen. 2009; http://www.et-energie-online.de/index.php?option=com_content&view=article&id=117:windenergieintegration-bei-negativen-strompreisen&catid=1:weitere-berichte-der-aktuellen-ausgabe&Itemid=10. Accessed 24 November 2009.
21. Wandler R. Planung des Unplanbaren. *Neue Energie.* Vol 1, 2010:84-87.
22. Vattenfall Europe Transmission. Intraday trading stopped - Grid congestion. 2009; http://www.vattenfall.de/cps/rde/xchg/trm_de/hs.xsl/SetWebsiteLanguage.xml?lang=en&targetPage=index.htm. Accessed 24 November 2009.
23. European Commission. *The Renewable Energy Progress Report. SEC(2009) 503,* 2009.
24. Ragwitz M, Held A, Resch G, et al. Assessment and optimisation of renewable energy support schemes in the European electricity market. Final report. Karlsruhe: Fraunhofer Institute for Systems and Innovation Research (ISI), Directorate-

General Transport and Energy (DG TREN), European Commission; 2007.

25. MVV Consulting. Implementation of TEN-E Projects (2004-2006). Evaluation and Analysis: European Commission, Directorate-General Energy and Transport (DG TREN); 2007.
26. European Network of Transmission System Operators for Electricity (ENTSO-E). Policy 1: Load-frequency control and performance, 2009.
27. Eurostat. EU Energy in figures. Electricity generation from Renewables. Extended time series: European Commission; 2009.
28. Richter C, Teske S, Short R. *Concentrating Solar Power. Global Outlook 09*: Greenpeace, SolarPACES, ESTELA; 2009.
29. Clean Technology Fund. Investment plan for concentrated solar power in the Middle East and North Africa region. 2009.
30. Barras L. *Renewable energy policy in Morocco - Its political potential for green electricity imports*, Freie Universität Berlin; 2009.
31. Brand B. Solar power from the Sahara - a vision? *Sun and Wind Energy.* Vol 1 (2008):28-39.
32. Platts. UDI World Electric Power Plants Database, 2008.
33. World Energy Council. Europe's Vulnerability to Energy Crises, 2008.
34. German Aerospace Center (DLR) Institute of Technical Thermodynamics SSAaTA. Concentrating Solar Power for the Mediterranean Region. Stuttgart 2005.
35. Williges K, Lilliestam J, Patt AG. Making concentrated solar power competitive with coal: the costs of a European feed-in tariff. *Energy Policy.* 2010; in press.
36. Pitz-Paal R, Dersch J, Milow B. ECOSTAR. European Concentrated Solar Thermal Roadmapping. Stuttgart: German Aerospace Center (DLR); 2004.
37. European Association for Coal and Lignite (Euracoal). Coal production and imports in EU-27 in 2007. 2008; http://www.euracoal.org/pages/medien.php?idpage=400. Accessed 7 April 2009.
38. Euratom Supply Agency. Euratom Supply Agency: Annual Report 20072008.
39. BP. Statistical Review of World Energy, 2009.
40. European Association for Coal and Lignite (Euracoal). Trade with hard coal in EU-27 in 2007, . 2008; http://www.euracoal.be/pages/medien.php?idpage=397. Accessed 7 April 2009.
41. Library of Congress. Country profile: Libya. 2005; http://lcweb2.loc.gov/frd/cs/profiles/Libya.pdf. Accessed 24 November 2009.
42. Library of Congress. Country profile: Algeria. 2008; http://lcweb2.loc.gov/frd/cs/profiles/Algeria.pdf. Accessed 24 November 2009.
43. U.S. Energy Information Administration. Libya. Oil. http://www.eia.doe.gov/emeu/cabs/Libya/Oil.html. Accessed 8 December 2009.
44. U.S. Energy Information Administration. Algeria. Oil. http://www.eia.doe.gov/emeu/cabs/Algeria/Oil.html. Accessed 8 December 2009.
45. Jochem E, Jaeger CC, Battaglini A, et al. Investitionen für ein klimafreundliches Deutschland. Potsdam, Karlsruhe: Potsdam-Institut für Klimafolgenforschung, Fraunhofer-Institut für Innovations- und Systemforschung; 2008.
46. oil-price.net. Crude oil and commodity prices. 2009; www.oil-price.net. Accessed 8 December 2009.
47. Organization of the Petroleum Exporting Countries (OPEC). *Annual Statistic Bulletin,* 2009.
48. RWE. *Renewable Technologies: Hydro,* 2008.
49. European Wind Energy Association. *European market for wind turbines grows 23% in 2006,* 2007.
50. Wind Energy. 2008. http://risoe-staged.risoe.dk/Research/sustainable_energy/wind_energy.aspx. Accessed 22 July 2008.
51. European Wind Energy Association. *Windmap,* 2008.
52. Hoogwijk M, de Vries B, Turkenburg W. Assessment of the global and regional geographical, technical and economic potential of onshore wind energy. *Energy Economics.* 2004; 26(5):889.
53. Schiermeier Q, Tollefson J, Scully T, Witze A, Morton O. News feature: Electricity Without Carbon. *Nature.* 2008; 454:816-823.
54. United Nations. *The promise of solar energy: a low carbon energy strategy for the 21st century,* 2007.

55. The Climate Group. *SMART 2020: Enabling the Low Carbon Economy in the Information Age,* 2008.
56. European Commission. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC, 2003.
57. European Commission. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market, 2001.
58. European Commission. Treaty of Lisbon amending the Treaty on European Union and the Treaty establishing the European Community, signed at Lisbon 13 December 2007.
59. European Commission. Climate Change. http://ec.europa.eu/environment/pubs/pdf/factsheets/climate_change.pdf. Accessed 24 November 2009.
60. European Commission. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 2009.
61. res-legal.de. Rechtsquellen Enerneuerbare Energien. 2009; http://www.res-legal.de. Accessed 14 October 2009.
62. EurActiv. Turmes: Seeks revamped renewables trading, rejects biofuels target. 2008; http://www.euractiv.com/en/energy/turmes-seeks-revamped-renewables-trading-rejects-biofuels-target/article-172326. Accessed 29 October 2009.
63. Nilsson M, Nilsson LJ, Ericsson K. The rise and fall of GO trading in European renewable energy policy: The role of advocacy and policy framing. *Energy policy.* 2009; 37(2009):4452-4462.
64. European Commission. The renewable energy progress report. SEC(2009) 503. Brussels: European Commission; 2009.
65. Bundesministerium für Umwelt Naturschutz und Reaktorsicherheit (BMU). Erneuerbare Energien in Zahlen. 2009.
66. Schmid J, Rohrig K, Braun M, et al. Wissenschaftliche Begleitung bei der fachlichen Ausarbeitung eines Kombikraftwerksbonus gemäss der Verordnungsermächtigung §64 EEG 2009. Kassel, Berlin: Institut für Solare Energieversorgungstechnik e.V.; 2009.
67. Mackensen R, Rohrig K, Emanuel H. Das regenerative Kombikraftwerk. Kassel: Institut für solare Energieversorgungstechnik (ISET); 2008.
68. European Energy Exchange (EEX). Emissionsrechte Spotmarkt. http://www.eex.com. Accessed 8 February 2010.
69. Matthes F. Nuclear Energy and Climate Change, 2005.
70. ExternE. Results of ExternE (Figures of the national implementation phase). 2008; http://www.externe.info/. Accessed 24 November 2009.
71. International Energy Agency. *World Energy Outlook 2005: Middle East and North Africa Insights,* 2005.
72. Lilliestam J. The creation of the pan-Nordic electricity market. Berlin, Potsdam: Freie Universität Berlin, Potsdam Institute for Climate Impact Research; 2007.
73. Amundsen ES, Bergman L. Integration of multiple national markets for electricity: The case of Norway and Sweden. *Energy Policy.* 2007; 35:3383-3394.
74. European Commission. *Report on progress in creating the internal gas and electricity market. SEC(2009)287,* 2009.
75. Sijm J, Neuhoff K, Chen Y. *CO_2 pass through and windfall profits in the power sector*: Electricity Policy Research Group (EPRG), University of Cambridge; 2006.
76. Bahrman MP, Johnson BK. The ABCs of HVDC transmission technologies. An overview of high voltage direct current systems and applications. *IEEE Power and Energy Magazine.* 2007; 5(2):32-44.
77. Baltic cable. Who, When and Where. 2009; http://www.balticcable.com/about.htm. Accessed 24 November 2009.
78. Neij L. Cost development of future technologies for power generation - A study based on experience curves and complementary bottom-up assessments. *Energy policy.* 2008;36 (2008):2200-2211.
79. European Wind Energy Association. *Wind Energy - The Facts,* 2009.
80. European Environment and Sustainable Development Advisory Councils (EEAC). Towards Sustainable European Infrastructures, 2009.
81. Stern N. *The Economics of Climate Change,* 2007.
82. B Savacool, Watts C. Going Completely Renewable: Is it possible (let alone desirable)? *The Electricity Journal.* May 2009
83. Victor D. *The Politics of Fossil Fuel Subsidies*: International Institute for Sustainable Development; 2009.

84. Renewables Grid Initiative. http://www.renewables-grid.eu/. Accessed 7 March 2010.

85. Ummel K, Wheeler D. *Desert power: the economics of solar thermal electricity for Europe, North Africa, and the Middle East.* Washington DC: Center for Global Development; 2008. Working Paper 156.

86. E.ON. Investments for Energy Security and Growth. 2009; http://www.eon.com/en/unternehmen/12513.jsp. Accessed 5 August 2009

87. Sagar AD, van der Zwaan B. Technological innovation in the energy sector: R&D, deployment, and learning-by-doing. *Energy Policy.* 2006; 34(17):2601.

88. Argote L, Epple D. Learning curves in manufacturing. *Science.* 1990; 247(4945):920-924

89. European Commission. *Strategic Energy Technology Plan,* 2009.

90. Desertec Industrial Initiative. 2009; http://www.desertec.org/.

91. European Commission. Euro-Mediterranean Partnership. 2010; http://ec.europa.eu/external_relations/euromed/index_en.htm Accessed 10 January 2010.

92. Major Economies Forum. *Technology Action Plan: Solar Energy - Report to the Major Economies Forum on Energy and Climate,* 2009.

93. Bliem M. *Eine makroökonomische Bewertung zu den Kosten eines Stromausfalls im österreichischen Versorgungsnetz*: Institut für Höhere Studien Kärnten (IHSK); 2005.

94. de Nooij M, Koopmans C, Bijvoet C. The value of supply security: The costs of power interruptions: Economic input for damage reduction and investment in networks. *Energy Economics.* 2007;29:277-295.

95. Regelleistung.net. Ausschreibungsergebnisse. 2009; https://www.regelleistung.net/regelleistungWeb/publicAusschreibungen/PublicAusschreibungenController.jpf. Accessed 24 August 2009.

96. Nordhaus W. *Managing the Global Commons,* 1994.

97. Nordhaus W, Boyer J. *Warming the world: economic modeling of global warming,* 2000.

98. Currie MJ, Mapel JK, Heidel TD, Goffri S, Baldo MA. High-Efficiency Organic Solar Concentrators for Photovoltaics. *Science.* 2008; 321(5886):226-228.

99. Metz B, Davidson O, Bosch P, Dave R, Meyer L, eds. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* 2007.

100. Hulme M, Neufeldt H, eds. *Making climate change work for us: European perspectives of daptation and mitigation strategies,* 2010. Hulme M, ed. ADAM book series.

101. Shindell D, Lamarque J, Unger N, et al. Climate forcing and air quality change due to regional emissions reductions by economic sector. *Atmospheric Chemistry and Physics.* 2008; 8: 7101-7113.

102. Earth Trends: The Environmental Information Portal. 2009.

103. U.S. Department of Energy (DOE). *Concentrating solar power commercial application study: Reducing water consumption of concentrating solar power electricity generation,* 2007.

104. German Aerospace Center (DLR). *Concentrating Solar Power for Seawater Desalinization,* 2007.

105. Sachs J, Warner A. Natural Resource Abundance and Economic Growth, 1995;No. 4398. Located at: NBER Working Paper Series.

106. Brunnschweiler CN, Bulte EH. Economics: Linking Natural Resources to Slow Growth and More Conflict. *Science.* 2008; 320(5876):616-617.

107. Stiglitz J. *Globalization and its Discontents,* 2002.

108. Parry ML, Canziani OF, Palutikof J, van der Linden P, Hanson C, eds. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press; 2007.

109. International Energy Agency (IEA). Projected Costs of Generating Electricity. 2005 Update: International Energy Agency (IEA), Nuclear Energy Agency (NEA), Organisation for economic co-operation and development (OECD); 2005.

110. Ötsch R, Haas A, Wirtz P, Zank S, Garz H. Deutsche Stromversorger - In der CO_2 Falle? 2009.

111. Kidd S. Escalating costs of new build: what does it mean? 2008; http://www.neimagazine.com/story.asp?sectioncode=147&storyCode=2050690. Accessed 24 November 2009.

112. Lovins AB, Sheikh I, Markevich A. Nuclear power: Climate fix or folly? *RMI solutions*. Boulder: Rocky Mountain Institute;

2008.

113. Márquez Salazar C. An overview of CSP in Europe, North Africa and the Middle East: CSP Today; 2008.

114. Sargent & Lundy. Assessment of parabolic trough and power tower solar technology cost and performance forecasts. Golden: Natiional Renewable Energy Laboratory (NREL); 2003.

115. Trieb F, O'Sullivan M, Pregger T, Schillings C, Krewitt W. Characterisation of solar electricity import corridors from MENA to Europe. Potential, infrastructure and cost. Stuttgart: German Aerospace Center (DLR); 2009.

116. Krohn S, Morthorst P-E, Awerbuch S. The economics of wind energy: European Wind Energy Association; 2009.

117. Klobasa M, Ragwitz M. Gutachten zur CO_2-Minderung im Stromsektor durch den Einsatz erneuerbarer Energien: Fraunhofer-Institut für System- und Innovationsforschung (ISI); 2005.

118. Kinstner R, Price HW. Financing Solar Thermal Power Plants. Paper presented at: Renewable and Advanced Energy Systems for the 21st Century Conference. 1999.

119. The World Factbook. Nigeria Pipelines Map. http://www.theodora.com/pipelines/nigeria_oil_gas_and_products_pipelines_map.html. Accessed 10 January 2010.

120. US Energy Information Administration. Select Transnational Gas and Oil Projects within Africa. http://www.eia.doe.gov/emeu/cabs/tbl4c.html. Accessed 10 January 2010.

121. ENI. Greenstream. 2009; http://www.greenstreambv.com/en/pages/company/company.shtml. Accessed 10 January 2010.

122. Stern J. The new security environment for European gas: worsening geopolitics and increasing global competition for LNG: Oxford Institute for Energy Studies; 2006.

123. Institute of Electrical and Electronics Engineers Transmission and Distribution Committee. *HVDC Projects Listings,* 2008.

124. ABB. Xiangjiaba - Shanghai HVDC Link. 2009; http://www.abb.com/cawp/gad02181/c0d40da9112e6856c12573b0004490f7.aspx. Accessed 12 January 2010.

125. ABB. Rio Maderia HVDC Link. 2009; http://www.abb.com/cawp/gad02181/9286c4b38c2401dbc12575f9002ffe48.aspx. Accessed 12 January 2010.

126. European Commission. *The support of electricity from renewable energy sources,* 2008.

127. Jacobsson S, Lauber V. The Politics and Policy of Energy System Transformation - Explaining the German Diffusion of Renewable Energy Technology. *Energy Policy.* 2006; 34:256–276.

128. E-Parliament. Success story: Feed-in tariffs support renewable energy in Germany. http://www.e-parl.net/eparlimages/general/pdf/080603%20FIT%20toolkit.pdf. Accessed 10 November 2009.

129. Finnish Energy Industries Press Release. Energy Year 2008. 2009; http://www.energia.fi/en/news/energy%20year%202008%20electricity.html. Accessed 28 November 2009.

130. Greenpeace. Italy: Electricity, Coal and Climate Change. 2005; http://www.greenpeace.org/raw/content/international/press/reports/italy-electricity-coal-and-c.pdf. Accessed 28 November 2009.

131. E.ON. Energy in the Netherlands (2005-6). 2006; http://www.eon-benelux.com/eonwww/publishing.nsf/Content/Energie+in+Nederland_English. Accessed 23 November 2009.

132. Nordel. *Nordel Annual Statistics,* 1988–2008.

133. Fingrid. Transmission Service from Russia to Finland. 2005; http://www.energyregulators.eu/portal/page/portal/EER_HOME/EER_INITIATIVES/ERI/Baltic/Meetings1/RCC_meetings/1st_Baltic_RCC_SG/DD/miniforumtallinn.pdf. Accessed 28 November 2009.

134. European Commission. Economic and Financial Affairs http://ec.europa.eu/economy_finance/euro/emu/index_en.htm. Accessed 8 February 2010.

Appendix 7: Contact information

1. PricewaterhouseCoopers (PwC) – www.pwc.com

Gus Schellekens

One Embankment Place,
London,
WC2N 4RH
United Kingdom

gus.schellekens@uk.pwc.com

+44 7711 828 845

Jo McDonnell

One Embankment Place,
London,
WC2N 4RH
United Kingdom

jo.mcdonnell@uk.pwc.com

+44 207 212 7991

2. Potsdam Institute for Climate Impact Research (PIK) – www.pik-potsdam.de

Antonella Battaglini

Telegrafenberg A31
14473 Potsdam
Germany

antonella@pik-potsdam.de

+49 1705 849229

Johan Lilliestam

Telegrafenberg A31
14473 Potsdam
Germany

johan@pik-potsdam.de

+49 331 288 2683

3. International Institute for Applied Systems Analysis (IIASA) - www.iiasa.ac.at

Anthony Patt

Schlossplatz 1
A-2361 Laxenburg
Austria

patt@iiasa.ac.at

+43 2236 807 306

Overview – today's situation: tomorrow's vision

The 2010 situation

- The power systems of Europe are dominated by fossil fuel (55%) and nuclear (30%) electricity. The North African power systems are made up of 67% gas and 20% oil power.
- By far the largest part of the renewable electricity comes from old hydro power stations. There has been some expansion of renewable energy, mainly onshore wind and biomass power, in Europe over the last 10 years but this has been focused on a few EU15 countries and the overall growth has been modest.
- The European grid is split into 5 asynchronous blocks connected with a few HVDC interconnections and the North African grid consists of two synchronous blocks. There is significant grid congestion, especially at national borders.
- The European power market is fragmented, consisting of a large number of national markets which are dominated by a few very large companies. Despite the trend towards closer cooperation between markets, the Nordic market remains the only international power market. The pricing at the European power exchanges is based on marginal costs. The North African markets are strictly national and strongly regulated.
- Most countries are self-sufficient in electricity, but very dependent on fuel imports. Less than half of the European power plant fuel comes from European sources. For Algeria and Libya, the situation is reversed: these economies are largely based on the income from the export of oil and gas.
- Electricity policy is still largely a national matter, rather than a European one. With the Lisbon Treaty, the EU Emission Trading Scheme and the Renewables Directive, the European dimension has gained importance, but the impact of this is not yet clear. All renewables support schemes and other renewables policy implementation instruments are still strictly national. National renewables targets are emerging in North Africa.
- Renewable electricity is still more expensive than conventional power, with the exception of wind power at very good sites, in part due to explicit and implicit subsidies for fossil and nuclear power. The renewables expansion in Europe is driven by national support schemes. Power subsidies in North Africa are a major expenditure for most governments and strongly distort the market for new renewable power plants.
- A renewable energy industry is emerging in Europe, and is rapidly gaining importance as an employer.

Our 2050 vision

- The electricity supply system of North Africa and Europe in 2050 is 100% renewable, following a continuous and steady transformation of the power system in parallel with sustained growth in demand.
- The grids of North Africa and Europe are strongly interconnected. This has been achieved through the reinforcement of the HVAC grid, a pan-European, cross Mediterranean overlay HVDC Super Grid and the introduction of Smart technologies and a Smart Grid, i.e. a SuperSmart Grid.
- The renewable power mix is geographically optimised, with production at the most suitable sites across Europe and North Africa. Wind generation in the windy North Sea region, concentrating solar power with storage in the sunny south, biomass and wind in the Baltic Sea region and eastern Europe, and hydro in the mountainous regions of Scandinavia and the Alps.
- The North African and European energy policies are aligned and cooperative. A stable and predictable policy framework has been vital in achieving a 100% renewable power sector, as have financial incentives and support mechanisms, but these are now phased out.
- The European power market is unified and united with the North African market. This has been achieved by the gradual unification of regional markets, which have grown organically over time. An additional market which recognises and rewards dispatchability has also been introduced.
- All renewable technologies in use have experienced significant reductions in capital and operational costs along with improvements in efficiency. They are now cost competitive. Their supply chains constitute a mature and strong industry and the renewable power sector is an important employer of skilled workers in both regions. Almost all citizens have access to affordable electricity, especially in North Africa.

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